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JOHN F. DASHIELL

UNIVERSITY OF NORTH CAROLINA

STUDIES IN CLINICAL PSYCHOLOGY

Volume III

EDITED BY

LEE EDWARD TRAVIS

UNIVERSITY OF IOWA STUDIES IN PSYCHOLOGY

CHRISTIAN A. RUCKMICK, EDITOR

No. XXII

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PRINCETON, N. J.

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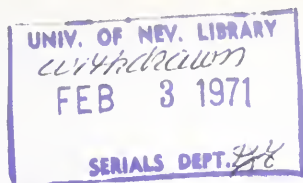
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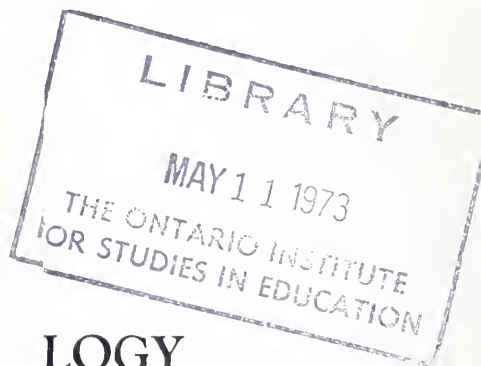
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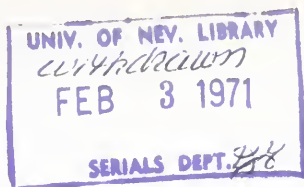
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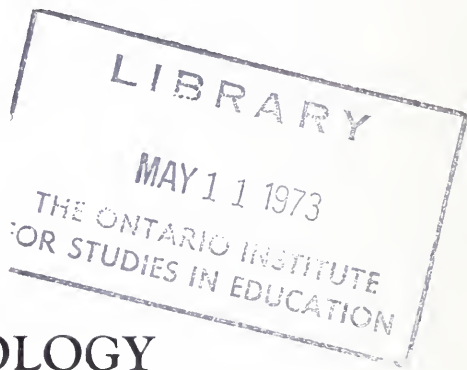


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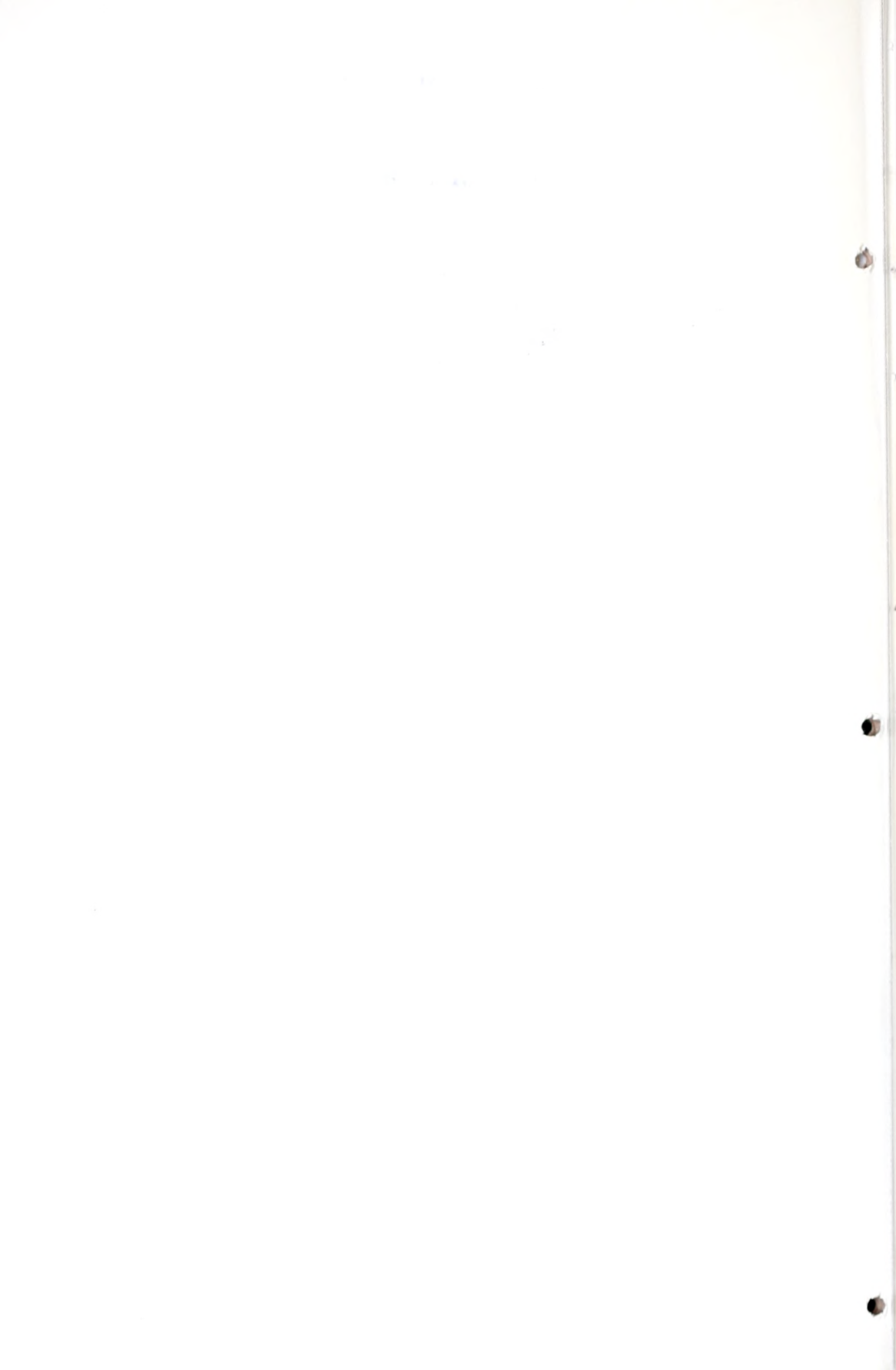
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PREFACE

This volume continues the practice of segregating the studies done in the various Psychological Laboratories of the University of Iowa. This number contains investigations completed under the guidance of Dr. Lee Edward Travis, director of the Psychological Clinic, and constitutes the third number issued in this field.

The monograph testifies to the continued productivity of the Psychological Clinic, which has already attained a high reputation for critical research work in the area of neuromuscular functions and their disturbances. While many of these experiments are directed to problems connected with vocal derangements, motor co-ordinations of related types have also been studied. Behind the specific researches lies a frame inclosing a complex picture of neuromuscular activities. Consequently these isolated studies are after all integrated in the direction of furnishing further facts towards the solution of a current problem pertaining to the psychophysiological organism.

The Editor of the Series is grateful to all the students and staff members who have brought their contributions into conformity with our studies for publication, but especially to Dr. Lee Edward Travis who has given this volume preliminary attention in an editorial capacity and to Mr. Claude E. Buxton who has painstakingly read the manuscripts and offered valuable criticisms.

CHRISTIAN A. RUCKMICK

Iowa City, Iowa
15 April, 1936



INTRODUCTION

The studies by Drs. Gardner, Hunsley, Morley, Strother, Bagchi, Hilden and Patterson are doctoral theses involving an analysis of stuttering and the neurophysiological processes underlying voluntary, conditioned reflex, and reflex behavior in man. The first four comprise a group attacking an important problem in clinical psychology, while the last three make their contributions to physiological psychology. Mr. Milisen includes a study on the effect of training upon handedness preferences of rats. A short paper on the problem as to whether a stutterer is affected in his speaking by listening to other stutterers is presented by Dr. Van Riper.

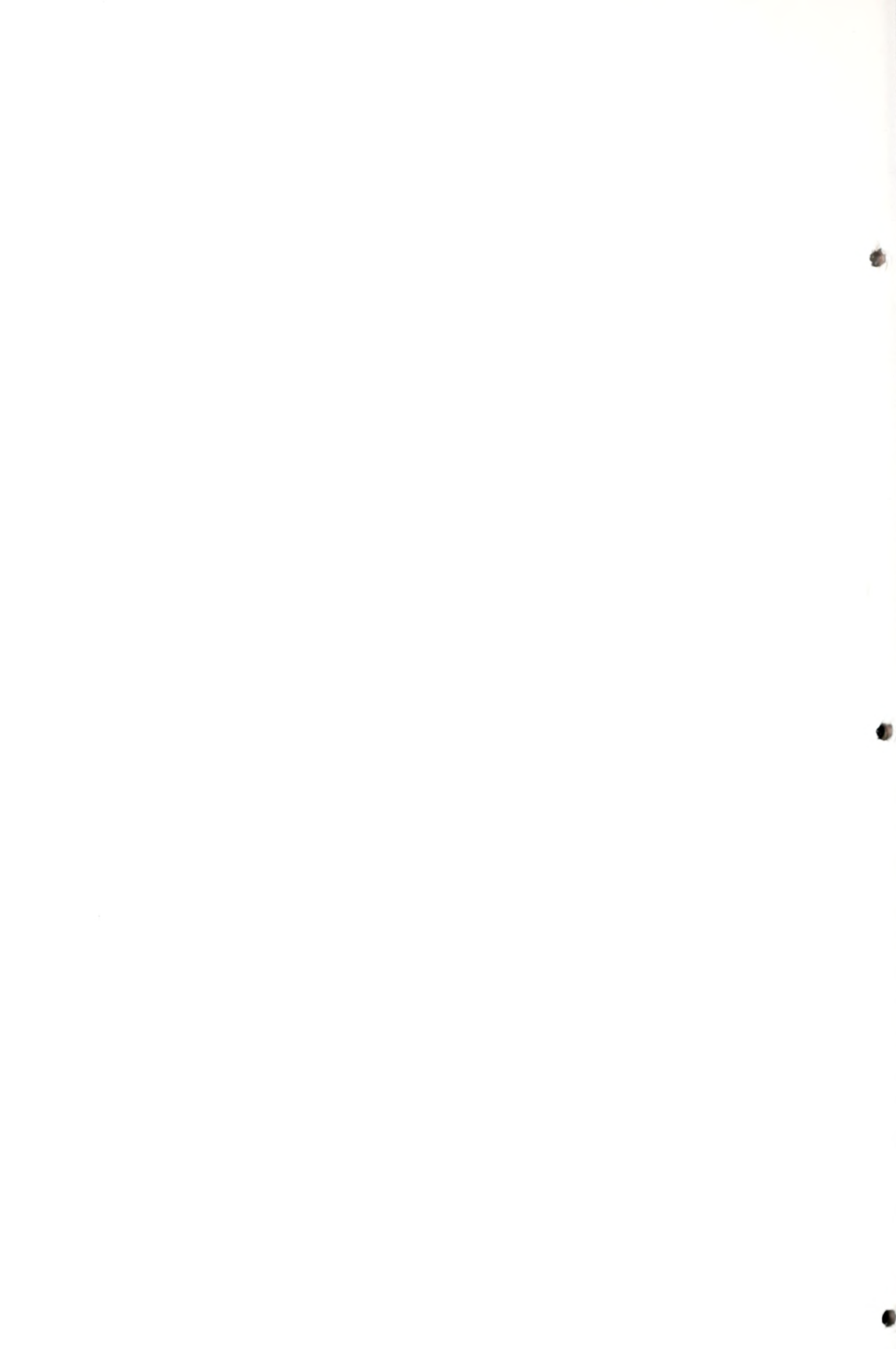
These investigations, all of which were done under the Editor's direction, continue a co-operative research program inaugurated for the purpose of studying both organic and functional neuromuscular derangements. Experimental rather than clinical procedures were utilized throughout.

The Editor of this volume wishes to record here his thanks to the Editor of the Iowa Studies, Professor Christian A. Ruckmick, for his generous and expert help in the preparation of the manuscripts for publication.

LEE EDWARD TRAVIS

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THE STUDY OF THE PUPILLARY REFLEX, WITH SPECIAL REFERENCE TO STUTTERING

by

WARREN H. GARDNER

I. Introduction. Research in speech pathology at the University of Iowa has been directed toward a better understanding of the neurophysiology of the speech and allied mechanisms. The directly observable symptoms have been measured and, furthermore, definite asynergies have been detected in the more subtle neuromuscular units which ordinarily produce normal speech.

Pupillary activities are source-material for studies of the functioning of the central nervous system. They are especially provocative to research because they are controlled through both the parasympathetic and sympathetic divisions of the autonomic nervous system. Normal synchronisms and antagonisms may be compared with disruptions which are instigated by laboratory technique or which are found to accompany abnormalities in other bodily functions.

II. Apparatus and technique. The apparatus consisted chiefly of a synchronous motor (Fig. 1) and motion picture camera in sound-proof housing; a photography and stimulus light of 450 foot-candles (Fig. 2); and head rests that rigidly but comfortably secured the head of *S* (Figs. 3 and 4).

The light source was stimulus for the pupillary reflex. For this experiment, the pupillary contraction to light while *S* was silent was considered the normal response. Extra-stimuli were speech, bell, electric shock (Fig. 1), gun shot, needle prick (Fig. 5), and hand contraction. These were administered shortly before the light.

The apparatus was installed in a small dark-room. No light was visible during dark adaptation except a tiny fixation light (Fig. 1). The apparatus and purpose of the experiment were

explained to S and he was placed in the dental chair. After he was securely fastened and his eye focused, a brief rehearsal of the photography was given. All lights were turned off and S was told to remain quiet. When the signal 'get ready' was

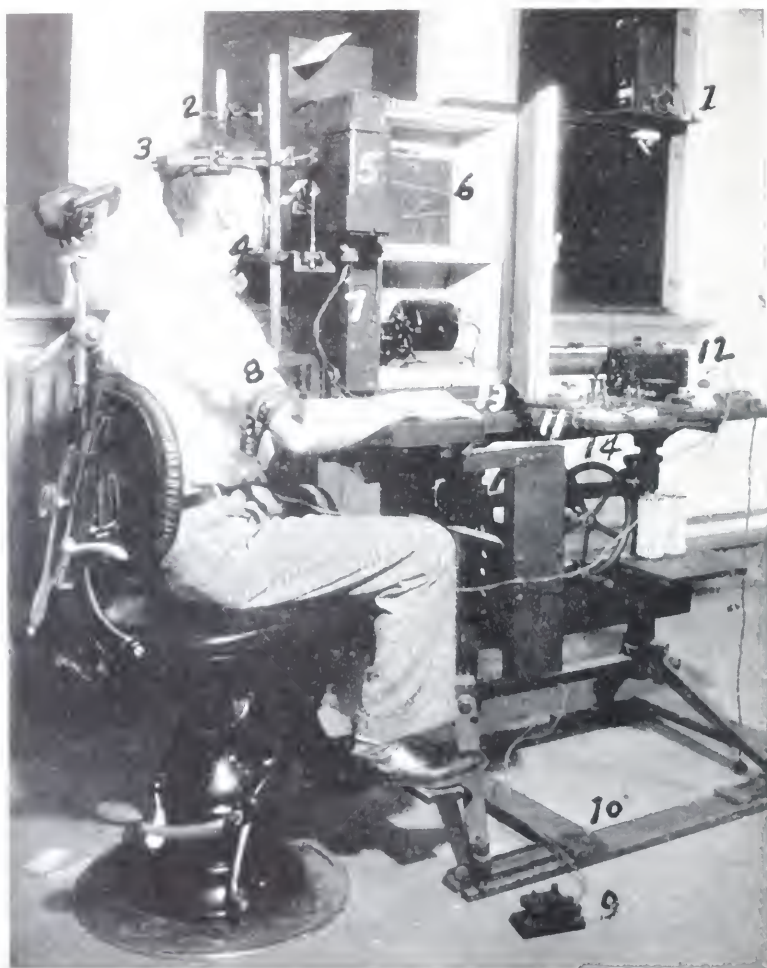


FIG. 1. Side view of cinematographic apparatus. (1) Fixation light box; (2) chin rest; (3) head rest; (4) chin rest; (5) light housing; (6) camera; (7) shutter release; (8) electric shock stimulator; (9) foot motor starter; (10) track for moving apparatus up to S; (11) switches for motor, light, bell, electric shock; (12) rheostats; (13) horizontal slide; (14) vertical adjuster. Apparatus was installed in a windowless room.

given, he fixated a cross with his left eye (bringing the right eye directly before the center of the lens). The signal 'now' followed shortly and immediately afterwards the light shone on

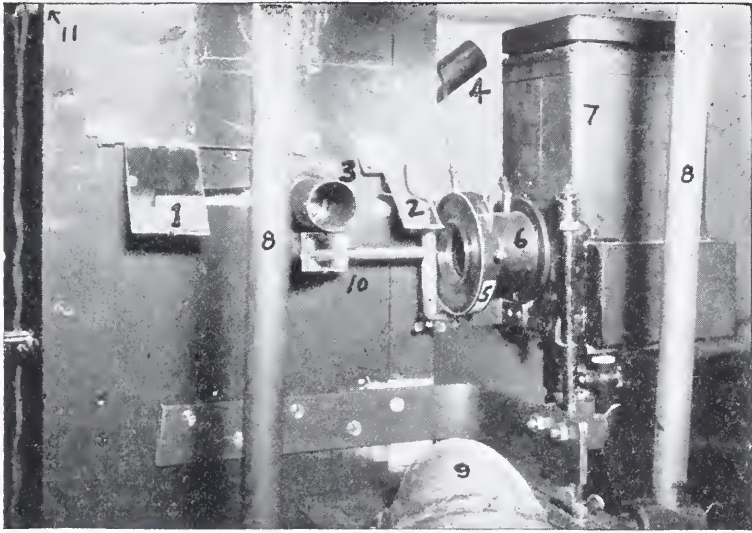


FIG. 2. Front view of cinematographic apparatus: (1) and (2) fixation mirrors for left and right eyes; (3) lens barrel; (4) focusing barrel; (5) silent shutter; (6) water cell; (7) light housing; (8) vertical shafts; (9) chin rest; (10) right angle mirror reflecting photography light from lamp housing into eye of S; (11) bell.

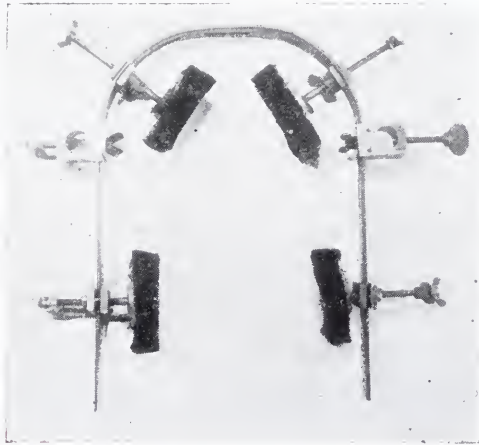


FIG. 3. Head rest; slides along vertical shafts

the right eye for 5 sec. When *P* was sure that *S* understood the procedure, a preliminary dark adaptation period of 5 min. was given. If, at the end of that period, *S* winked badly or rolled



FIG. 4. Upper left: chin rest, slides along vertical shafts. Lower right: camera lens attachment, fixed to lens barrel at (a); used to bring front of eye into exact focus.



FIG. 5. Skin needle stimulator. As needle contacts flesh, electrodes on contacts leave the spring come together, completing a circuit which lights camera lamp to indicate on film the exact moment stimulus was applied. Needle stimulator: the lower plate is raised by gas expansion and completes the circuit for the signal lamp.

his eye when the light was presented, he was not used further. If he was acceptable, he remained in the chair 10 min. longer, at the end of which time the pupillary contraction was photographed

He was released from the chair, rested for 5 min. in an outer room, was reseated, and the second photography followed. Not more than four photographs were taken in one series and only one series a day.

With certain exceptions to be noted later, *Ss* were photographed at the same period of the day, namely, between 8:30 and 10:30 A.M. During the trials with speech, *S* was requested to start speaking a few moments before photography began, just before expiration of the 10 min. dark adaptation period. Instead of saying 'get ready,' *E* said 'start speaking' and shortly afterward gave the signal 'now.'

The standard form of speech was:

"My name is John Jones. I am 20 years old. I was born in Byron, Illinois, and graduated from East High School, Des Moines. I am now attending the University of Iowa, in the graduate college."

Photography of the pupillary contraction during speech of normal speakers was comparatively easy. It was most difficult with stutterers. Two methods were used with the latter. Some stutterers stuttered most frequently on certain words, such as their names or the names of their places of residence. In such cases the stutterer was asked to pronounce these words at the signal 'now.' *S* usually was photographed while he was having a block. In working with the group who stuttered only occasionally during speech *E* had to wait until *S* was in a distinct, prolonged block before the signal 'now' was given. In such cases only records obtained at the end of 10 min. adaptation periods were used.

The projection apparatus (Eastman Kodatoy) was used in measuring pupillary diameters. The correlation between a first reading of 127 frames representing a complete pupillary contraction (Fig. 6) and a second reading by the same person was .99.

III. Subjects. Fifty-four *Ss* were used. Thirty were normal speakers; 21 were stutterers. One normal male was 75 yrs. old. Two boys were 10 and 12 yrs. old. Ages of 51 *Ss* ranged from 17 to 35 yrs. Nine normal speakers and five stutterers were

tenales. All stutterers were attending the speech clinic at the University of Iowa. Seven normal speakers were undergraduates and the remainder were graduate students in psychology and speech. It was impossible to obtain comparative figures from all Ss, largely because of occasional winking or failure to fixate. Especially was this true of the stutterers, many of whom showed the eye-wink in conjunction with other overlaid manifestations of the stuttering spasm. Twenty additional stutterers were not used finally because of severe blinking, jerking of head and



FIG. 6. Enlargement of 16 mm. negative supersensitive panchromatic film. Large dark center, pupil; mottled gray area, iris; white spot in center of pupil, reflection of photographic light.

rolling of eyes during preliminary tests. The majority of Ss were blue-eyed and were photographed at the rate of 24 frames per sec.; the remainder were brown- or gray-eyed and were photographed at 12 frames per sec.

III. Results

The Normal Pupillary Response to Light

Latent time. The latent time is the interval between the instant the light strikes the eye and the moment of initiation of constric-

tion of the pupillary margin. Fifty-one Ss showed the latent times given in Table I. The average for all Ss was .237 sec.

TABLE I. *Latent times of normal pupillary reflex*

	.167 sec.	.201 sec.	.25 sec.	.292 sec.
Normal speakers	0	8	20	2
Stutterers	3	3	15	0
Total	3	11	35	2

Weiler (9) reported the latent time to vary from .15 to .28 sec.; *Reeves* (8) stated it was .20 sec.; and *Gradle* (6) reported it to be .1875 sec. *Reeves* reported on seven cases; other investigators did not indicate the number of cases. In this study, 28 per cent were in agreement with the figures of these investigators. Several factors may be responsible for differences in latent time: (1) the number of frames per sec.—true initiation of contraction might be between two frames exposed successively, which would be detected only at twice the speed; (2) different intensities of light—*Reeves* used a battery of lamps for his photography, *Gradle* an arc lamp, and *Weiler* a Nernst lamp. The present photography was done under an illumination intensity of 450 foot-candles.

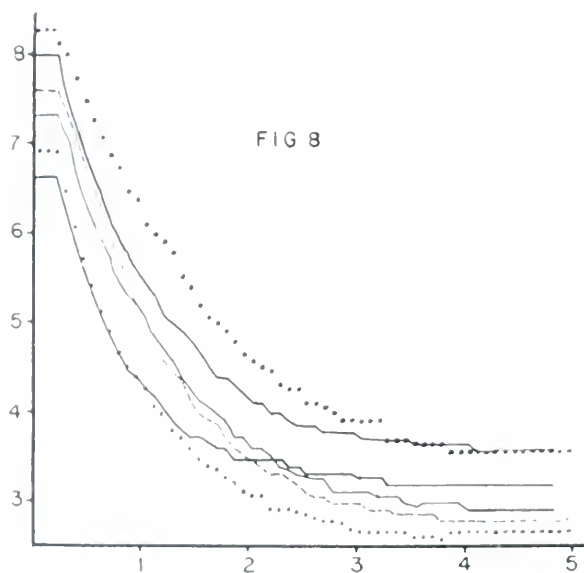
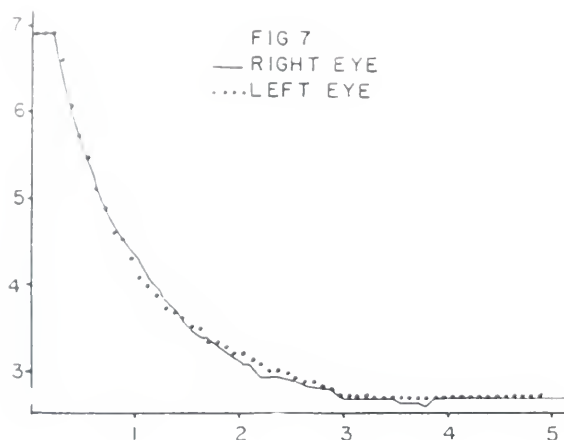
The latent time was consistent for each *S* with very few exceptions. Measurements were obtained at least twice for all *Ss* and four times for the majority. Hence the latent time was obtained in at least 300 different pupillary responses. The latent time remained consistent from day to day, hour to hour, and in immediately successive responses, all under the same light intensity. The latent time of the two young boys was .25 sec., of the aged man, .33 sec.

Size of the pupil. After 10 min. of dark adaptation following exposure for 5 sec. to a light-intensity of 450 foot-candles, the right pupil of 41 *Ss* averaged 7.54 mm., with a range of 6.6–8.8 mm. The figures for right and left pupils of 28 *Ss* are shown in Table II. The difference between right and left pupils is

TABLE II. *Dilated pupillary diameters in mm. of right and left eyes*

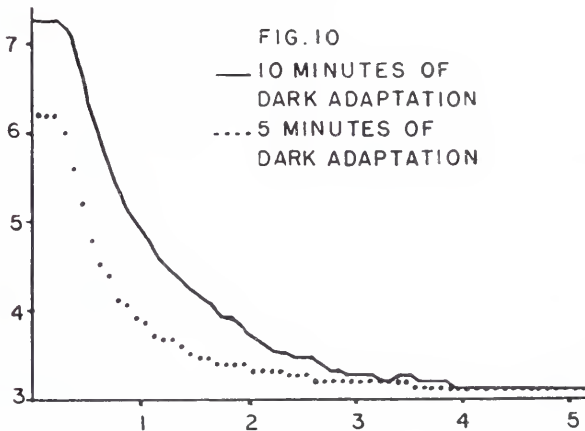
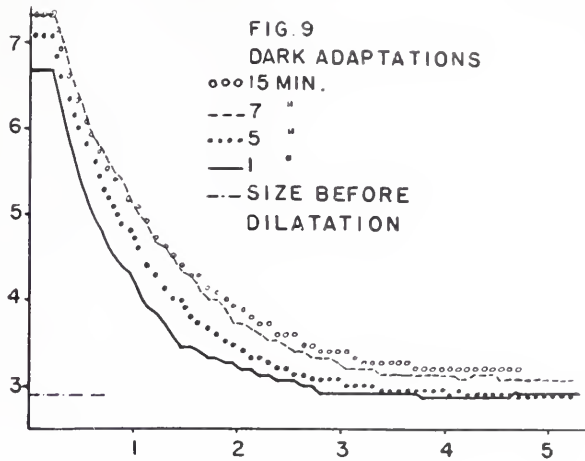
	Right eye	Left eye	Range	N
Normal speakers				
Male	7.82	7.77	7.07–8.80	11
Female	7.41	7.33	6.70–8.13	9
Av.	7.64	7.56	6.70–8.80	20
Stutterers	7.43	7.31	6.00–8.44	8
Av. all cases	7.58	7.50	6.00–8.80	28

(8 mm.) for 28 cases, including stutterers. The right and left pupils of 11 (40 per cent) were identical. Fig. 7 demonstrates the similarity of pupillary responses of the right and left eyes of I.P.



FIGS. 7-8-9-10. Pupillary responses to light; time in seconds represented along abscissa, diameter in mm. along ordinate. Fig. 7, responses of M.K. right and left eyes, during silence, within a half hour period. Dark adaptation 10 min. for each. Fig. 8, responses of six female normal

Weiler (9) stated that the physiological diameters of the right and left pupils were equal, but measurements by other investi-



speakers during silence, 10 min. dark adaptation, same time of day. Fig. 9, responses of OA during silence after varying periods of dark adaptation obtained within a period of one hour. Fig. 10, normal response of WD, after periods of 5 and 10 min. dark adaptation, both within a period of one-half hour.

gators have indicated that two to 40 per cent of Ss (2) showed differences between right and left eyes. Exact comparison of results is impossible as long as conditions are not identical. The physiological diameter often reported by those in clinical practice

to 3.00 mm. after several minutes' adaptation to a light such as that coming through a window. Other investigators used different intensities and techniques as well as different times of adaptation. *Keeser* used 15, *Weiler* 10, and *Gradle* three minutes of dark adaptation.

Table II also shows the differences in pupillary diameters of 2088. The average diameter of the male right pupil was .41 mm. larger than the female; the average diameter of the left pupil was .44 mm. larger than the female. For the right pupil the range of the male was 7.07–8.80 mm., whereas the range of the female pupils was 6.7–8.13 mm. *Duke-Elder* (2) reported that the normal pupillary diameter of the female is larger than the male but the conditions mentioned in the last paragraph apply. Fig. 8 demonstrates the extreme ranges of pupillary responses of female normal speakers. Similar extremes can be demonstrated for male normal speakers and stutterers.

Size of pupil and age. The relationship between size of pupil and age was determined by the method of rank-differences, $r = .70$, which, transmuted by *Garrett's* (4) Table XX into the product moment coefficient, becomes $r = -.52$ for 22 normal speakers; for 22 stutterers, $r = -.39$. These figures point to a tendency for the younger person to have the larger dilatation. The statement is made more significant when results from photography of the dilated pupillary diameter of the right eyes of two young boys and an aged man are submitted. The 12-year-old boy's pupillary diameter was 9.07 mm., the 10-year-old's was 8.80 mm. That of the 75-year-old man was 6.27 mm. These figures are at opposite extremes of the range for 11 cases, given above. *Duke-Elder* (2) reports that the normal pupillary diameter of the aged and the young is small, but he refers again to the physiological diameter as explained above.

However, it is impossible to assign a specific pupillary diameter to a given age, using these figures. For example, four 22-yr. old males had pupillary diameters respectively of 6.00, 6.80, 7.47 and 8.13 mm. Five 19-yr. old males had diameters respectively of 6.00, 6.87, 7.47, 7.73 and 8.13 mm. It appears that within the age brackets of 18 to 25 yrs., in which the majority of S-

were, it would be difficult to obtain a high correlation between age and dark-adapted pupillary diameter.

Pupillary diameter and length of adaptation. The pupil dilates most rapidly in the first 10 secs. and much more slowly thereafter (see Table III). In the case of OA (Fig. 9) the pupil

TABLE III. *Effects of varied periods of dark adaptation of right eyes of OA and HF, diameters in mm.*

OA		HF	
Period	Diameter	Period	Diameter
0 min.	2.93	0 sec.	3.05
1	6.67	10	5.60
5	7.07	20	6.53
7	7.33	1 min.	6.93
15	7.33	3	7.20
		5	7.47

after 7 min. was just the same size as after 15 min. However, the pupil usually widens with increasing intervals of time; it continues to enlarge slightly (5) over periods ranging from one hour to eight hours. Table IV shows that in all trials except

TABLE IV. *Pupillary diameters in mm. after five and 10 min. dark adaptation periods, both within one-half hour*

Subject		5 min.	10 min.
WD	Trial A	6.20	7.27
	B	6.60	7.33
	C	7.47	7.73
	D	6.93	7.47
DD		6.87	7.47
HW		7.73	7.87
RY		7.67	7.53
CB		8.07	8.07

two the pupillary diameter at 5 min. was smaller than that at 10 min. In one case the diameters were equal; in another, the diameter at 10 min. was smaller. Fig. 10 is a typical example of the pupillary responses after 5 and 10 min. periods of dark adaptation. A special routine was administered to one S. He was brought in from outdoors where the sun was shining brightly in a clear sky and was dark adapted for 5 min. His pupillary diameter was 6.93 mm. He stepped out into the sunshine again for 10 min. and then returned to be dark adapted for 7 mm. The pupil measured 7.13 mm. He returned to the

roomlight, stayed there for 10 min., returned to the chair and was dark adapted for 10 min. The diameter was 7.05 mm. Now, without leaving the chair, he was dark adapted for 10 min. and the diameter was 7.05 mm. These observations point to marked variations in the size of the pupil at the end of 5 min. dark adaptation, but the 10 min. period, as recommended by *Heiler* (9), should be sufficient to eliminate disturbing factors that might have preceded a given period of dark adaptation.

Consistency in size of pupil at different times. Pupillary diameters are not always the same between extended intervals of photography. Fig. 11 and Table V indicate the day-to-day

TABLE V. *Diameters in millimeters of O.A.'s right pupil after 10 min. dark adaptation at the same hour of day for seven successive days (8:30 A.M.)*

Thursday	7.27
Friday	7.33
Saturday	7.07
Sunday	7.33
Monday	6.93
Tuesday	7.07
Wednesday	7.07

variation in pupillary diameter of the same *S.* Fig. 12 indicates the variation in pupillary diameters of O.A. and seven other *Ss.* O.A. had a diameter of 7.07 mm. on three days while W.D. had a diameter of 7.47 mm. on five days, which might indicate that these are their normal pupillary diameters under conditions of the experiment. O.A.'s pupillary diameter was the same on two successive days and W.D.'s was the same on three. The pupils of none of the others were the same on two successive days. The ranges of variation were 13–40 mm. We can conclude that the pupillary diameter is not the same size from day to day. In fact, *Laukush* and *Moss* (7) reported that the pupil grows larger, for clerical workers, from the beginning to the end of the week, due to ocular fatigue, but decreases over the week-end rest period. So environmental conditions and physical activities may influence the diameter from day to day. Hence, if any comparisons are to be made of normal pupillary responses with responses accompanied or preceded by extra-stimuli, both types of responses should be photographed in the same series of trials within a period of not more than 100 hours.

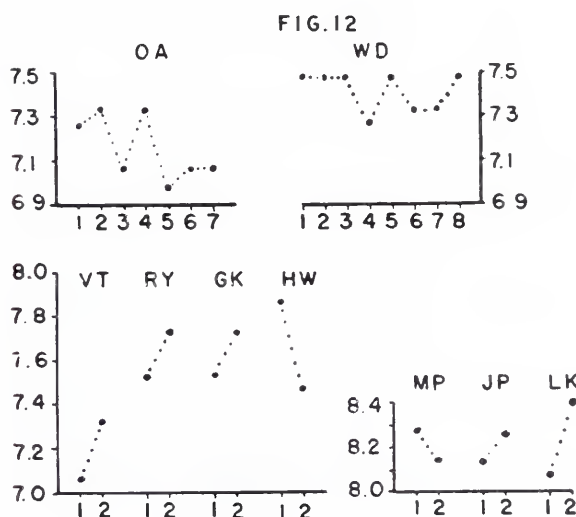
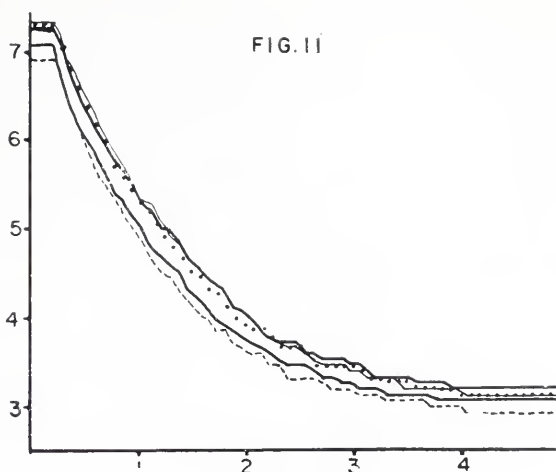
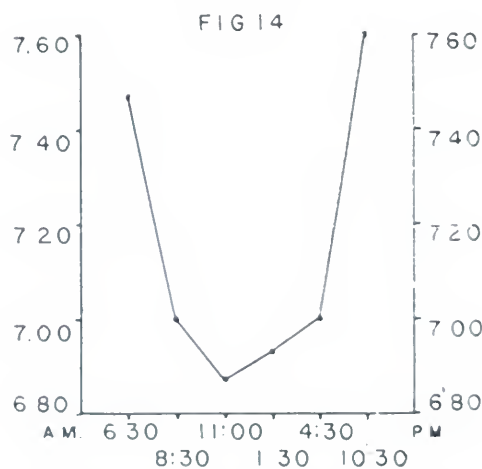
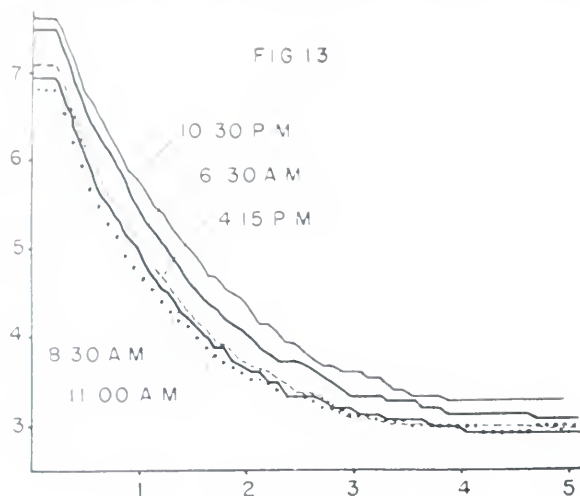


FIG. 11. Normal pupillary response of OA to light on five successive days at same time of day, each after 10 min. dark adaptation. Time in secs. represented on abscissa, diameter in mm. on ordinate. FIG. 12, changes in pupillary diameter after 10 min. dark adaptation, day to day, same time of day; $N=9$. Numerals on abscissa indicate number of days; letters indicate S's. Diameter in mm. represented along ordinate. FIG. 13, normal pupillary response of OA to light at different hours of same day, each after 10 min. dark adaptation. Time in secs. along abscissa; diameter in mm. on ordinate. FIG. 14, dilated diameter of pupil, 10 min. dark adaptation, at different hours of same day. Axes as in FIG. 13.

(Diameter of pupil at different hours of day) Figs. 13 and 14 indicate the variation in diameter that takes place from early in the morning, 6:30 A.M., to 10:30 P.M. at night. The range for



O.A. was 67 mm. The pupillary diameter at 10:30 p.m. was such that S believed the light to be twice as strong as in previous trials. Another S showed a diameter of 7.47 mm. at 8:30 a.m. and a diameter of 8.0 mm. at 8:30 p.m. These measurements indicate the necessity for keeping a constant time of experimentation.

Diameter of pupil in immediately successive periods. It must not be inferred that the pupillary diameter is never the same in successive periods of adaptation. Table VI indicates the fre-

TABLE VI. *Diameters, in mm., of right pupils after two 10 min. periods of dark adaptation within one-half hour*

Subject	1st period	2nd period	Diff.
RS	8.00	7.93	— .07
JS	8.27	8.27	...
MC	6.67	6.73	+ .06
VT	7.07	7.07	...
MNK	7.13	6.93	— .20
FD	7.60	7.60	...
AS	7.33	7.33	...
EM	7.33	7.33	...
JC	8.13	8.13	...
HW	7.47	7.47	...
LP	8.27	8.27	...
DS	8.80	8.80	...
OB	7.20	7.47	+ .27
OA	7.47	7.47	...
CH	7.07	7.07	...
DD	7.47	7.47	...
LK	8.40	8.27	+ .13
MP	8.27	8.27	...
BE	7.60	7.73	+ .13
NK	8.13	8.13	..

quency with which this phenomenon is present. Out of 20 cases of two successive exposures for each S, 14 were identical in pupillary diameters. This would indicate that if approximately 70 per cent of the cases ordinarily can be duplicated, as demonstrated in Fig. 15, then a significant reduction in this percentage under conditions of extra-stimuli accompanying the normal pupillary response should indicate the influence of factors aside from light stimulation.

Contraction time of pupil. Contraction time for purposes of this experiment extends from the end of the latent time, *i.e.*, when the initial contraction occurs, until the contraction reaches the lowest point for the first time. For 28 cases (see Table VII)

TABLE VII. *Contraction time in sec. of right and left pupils*

	Right eye	Left eye	Range	N
Normal speakers				
Male	3.58	3.58	.....	12
Female	3.52	3.27	.....	8
Total	3.56	3.45	2.63-4.17	20
Stutterers	3.83	3.67	2.79-5.17	28
Av. all cases	3.64	3.51	2.63-5.17	28

the contraction time was 3.64 sec. for the right pupil and 3.51 sec. for the left pupil. *Wilder* reported this time to be .67 sec. (9), *Conner* (5) reported it to be around 3.5 sec. *Reeves* (8) reported an average time of 3.6 sec. for eight cases with a range of 2.6–4.3 sec. *Bender* (1) reported an average constriction time of 3.51 sec. The figure of 3.64 sec. for the right pupil is practically equal to that reported by *Reeves*, but the range has been increased with 20 more cases. It should be noted that the range of the stutterers is greater.

Amount of contraction for first second. Investigators have mentioned the fact that the largest and fastest portion of the contraction occurs in the first .75 sec. (*Reeves*, 8) or during a period lasting .4365 sec. (*Gradle*, 6). Since these are arbitrary estimates and in practically all cases the largest portion of the contraction is completed in the first second, a study of the absolute amount of contraction over this longer period should reveal variations in speed of pupillary contractions under different conditions. The contraction during the first second was 2.75 mm. for the right and 2.88 mm. for the left pupil, with a range of 1.80–3.53 mm. (see Table VIII). *Reeves* (8) reported an

TABLE VIII. Amount of contraction in mm. for first second

	Right eye	Left eye	Range	N
Normal speakers				
Male	2.82	2.91	2.13–3.53	11
Female	2.90	2.93	2.33–3.27	9
Av.	2.86	2.92	2.13–3.53	20
Stutterers	2.51	2.79	1.80–3.26	9
Av. all cases	2.75	2.88	1.80–3.53	29

average of 2.6 mm. for eight cases, range 2.1–3.0, but this is not strictly comparable because he included the latent time in the first second of contraction.

Total amount of contraction. The total amount of contraction is the amount that the pupil constricts from its dilated diameter to the lowest diameter reached during the contraction. The average total amount for 26 cases was 4.54 mm. for the right pupil and 4.38 mm. for the left, with a range of 3.20–5.34 mm. *Reeves* reported an average of 4.8 mm. with a range of 3.0–5.5 mm. but he used a 15 minute dilatation. Furthermore, he

used a battery of electric lamps for photography, which may have caused a greater contraction.

The minimum diameter of the pupil. The minimum diameter of the pupil is not necessarily the physiological minimum. For the purposes of this experiment, it is the point below which the pupil ceases to constrict during its response to a light stimulus lasting five seconds. As has been reported earlier, the minimum point is reached on the average with 3.64 sec. from the initiation of contraction under a constant stimulus of 450 foot-candles. The average minimum diameter of the pupils of 27 Ss was 3.13 mm. for the right eye and 3.10 mm. for the left (see Table IX). The range was 2.53–3.73 mm. *Reeves'* figure was

TABLE IX. *Minimum diameter in mm. of pupil at end of constriction to light stimulus of 450 foot-candles*

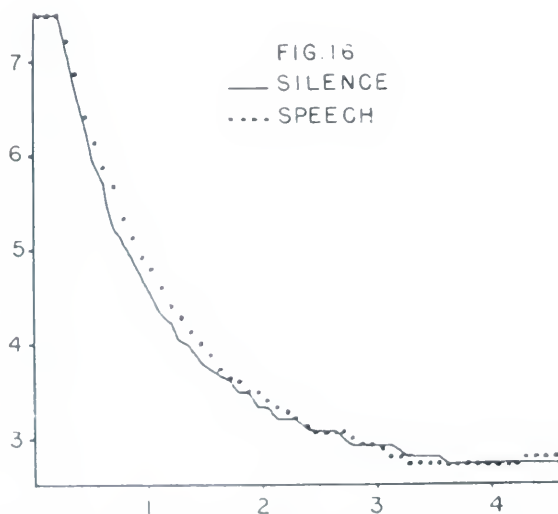
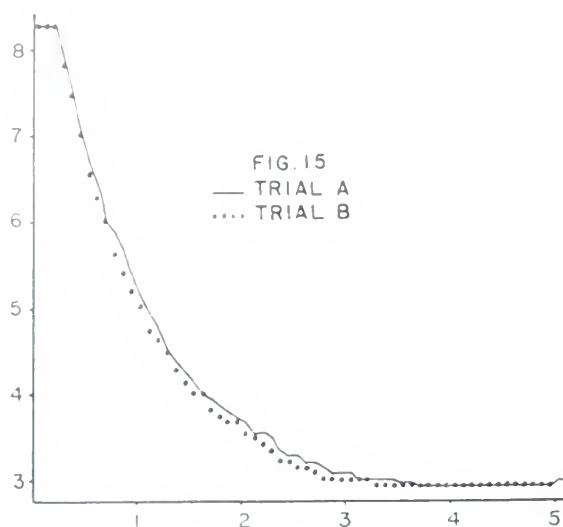
	Right eye	Left eye	Range	N
Normal speakers				
Male	3.20	3.19	2.53–3.73	11
Female	3.07	3.01	2.65–3.55	8
Av.	3.15	3.11	2.53–3.73	19
Stutterers	3.08	3.05	2.80–3.53	8
Av. all cases	3.13	3.10	2.53–3.73	27

3.36 mm. for eight cases only, with a range of 3.1–3.9 mm. The net result here was to lower the minimum diameter and to extend the range of *Reeves'* figures. The interesting fact is that the average minimum pupillary diameter of the left eye was only .03 mm. less than the right eye, a difference that is smaller than the average dilated diameter of the right and left pupils.

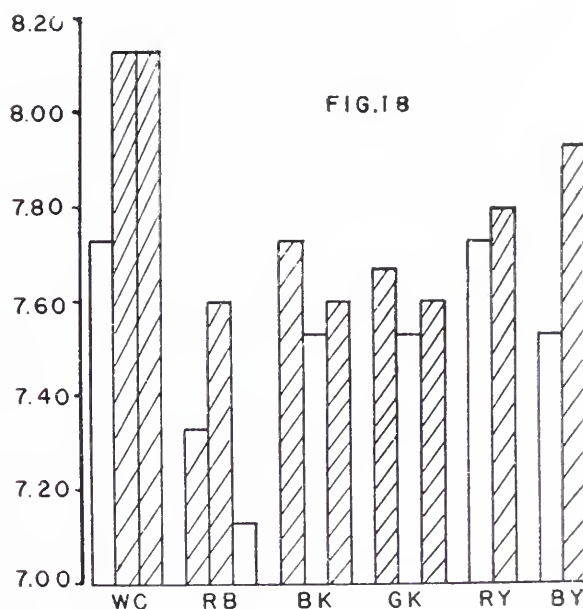
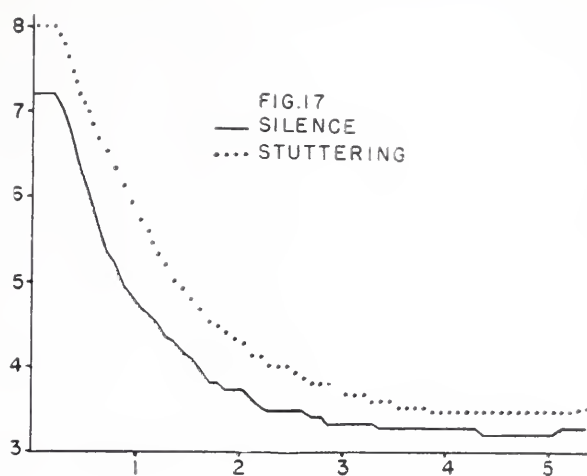
The Effect of Speech on the Pupillary Reflex

Dilated diameter. Thirteen normal speakers were dark adapted twice within one-half hour, once in silence and once with speech occurring just prior to and during the photography of the contraction (Table X). Seven of the 13 Ss (54 per cent) showed no change from silence during the act of speaking (Fig. 16). Three showed decreases from silence and three showed increases in the pupillary diameter. The mean diameter during silence was exactly the same as the mean during speech.

Seventeen stutterers were dark adapted twice within one-half hour. Their pupillary responses were photographed once while



Figs. 15-16-17. Pupillary responses to light, time in secs. is represented on abscissa, diameter in mm. on ordinate. Fig. 15, responses of MP, during silence and within a half hour period, dark adaptation was 10 min. Fig. 16, responses of DD, a normal speaker, during silence and speech, during a half hour period, dark adaptation was 10 min. Fig. 17, responses of WD, a normal speaker, during silence and uttering. Spasms were occurring



prior to and during the photography. Fig. 18, diameters of six stutterers after 10 min. dark adaptation, under conditions of silence and stuttering. In speech trials, spasms were occurring prior to and at the moment of photography. Along the abscissa the letters indicate *Ss*; along the ordinate the figures indicate diameter in mm. Cross-hatched bars indicate diameter during stuttering; blank bars indicate diameter during silence.

TABLE X. *Pupillary diameters of normal speakers in mm. under conditions of silence and speech; 10 min. dark adaptation*

Subject	Silence	Speech	Diff.
YAL	8.53	8.53	...
BS	8.67	8.80	+ .13
DL	7.47	7.47	...
DLH	7.73	7.73	...
GL	7.20	7.07	- .13
LH	7.07	7.20	+ .13
LW	7.47	7.47	...
RS	8.00	8.00	...
YL	7.07	7.07	...
BL	7.73	7.60	- .13
MP	8.13	8.13	...
IS	8.27	8.13	- .14
CA	7.17	7.36	+ .19
AV	7.73	7.73	...

they were silent prior to and during the photography, and again while they were endeavoring to speak, i.e., were having stuttering spasms prior to and during the photography. Fig. 17 shows the pupillary diameters of a stutterer during speech and silence. It is noticeable that the pupillary diameter was larger during the stuttering than during silence. Table XI supports this statement in a more convincing manner. When the stuttering spasm was present during speech, the average pupillary diameter of 17 Ss was .25 mm. greater than when they were silent. According to

TABLE XI. *Dilated diameters in mm. under conditions of silence and stuttering; 10 min. dark adaptation*

Subject	Silence	Stuttering	Diff.
JR	7.73	8.13	+ .40
LL	6.00	6.60	+ .60
KB	7.47	7.60	+ .13
GK	7.53	7.73	+ .20
HL	7.13	7.33	+ .20
JM	6.87	7.07	+ .20
MD	8.40	8.67	+ .27
GE	7.60	7.73	+ .13
WC	7.73	8.13	+ .40
IW	7.47	7.73	+ .26
LW	8.53	8.67	+ .14
FAA	7.73	7.87	+ .14
BP	6.00	6.13	+ .13
WD	7.47	7.87	+ .40
PG	6.13	6.40	+ .27
RY	7.63	7.87	+ .24
LM	7.87	8.00	+ .13
AV	7.37	7.62	+ .25

*Fisher's*¹ tables (3), the chances are 93 in 100 that this difference is significant, compared with no difference between silence and normal speech. One hundred per cent of the cases showed increases in pupillary diameter during the stuttering spasm, as compared with 23 per cent (three of 13) normal speakers who showed an increase, while three others showed a decrease.

Table XI and the bar graphs in Figs. 18 and 19 indicate a

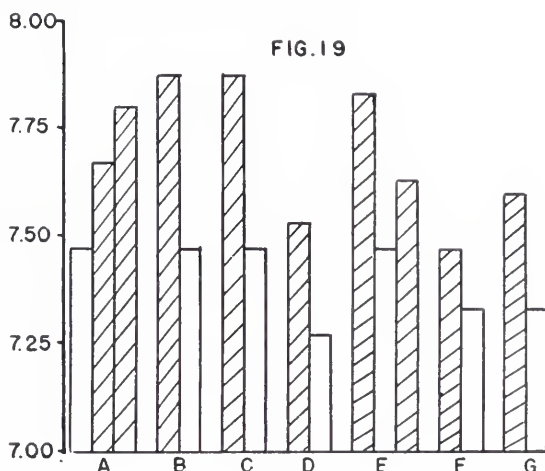


FIG. 19. Pupillary diameters of one stutterer after 10 min. dark adaptation on seven days at same time of day, under conditions of silence and stuttering. In the speech trials, spasms were occurring prior to and during the photography. Along the abscissa the letters indicate days. Cross-hatched bars indicate diameters during stuttering; blank bars indicate diameter in silence.

definite and significant increase in the dilated pupillary diameter during the stuttering act. But that an increase is present in normal speech of some normal speakers is revealed by Table XII. Apparently there are those among the normal speakers who show the same tendency as the stutterers, whatever the factor may be in both groups of speakers.

¹ The significance of a difference between means of two measurements of the *same small sample* can be obtained by the method of *Fisher* (3, p. 105). In this instance, where *N* is small and one has given the means of measurements of the pupil during silence and during speech, the degree of significance of the obtained difference is expressed as chances in 100 that it is significant.

TABLE XII. Amount of contraction in mm. under conditions of silence and speech after 10 min. of normal speakers on five different days

	Silence	Speech	Diff.
	7.07	7.20	+ .13
	7.33	7.47	+ .13
	7.33	7.60	+ .27
	7.07	7.20	+ .13
	7.07	7.33	+ .26
A	7.17	7.36	+ .19

Contraction time. Contraction time was affected to a slight extent by the stutterers' speech:

	Silence	Speech	Diff.	N
Normal speakers	3.58 sec.	3.656 sec.	-.076	9
Stutterers	3.48	3.38	+ .10	12

According to *Fisher's* tables, the chances that the difference between silence and speech of normals is significant are 12 in 100, whereas the chances that the difference between silence and speech of stutterers is significant are 69 in 100. Furthermore, the contraction time of normal speakers in speech is less than that of silence in 34 per cent of the cases ($N=9$), whereas the contraction time of stutterers during their attempted speech is less than that of silence in 75 per cent of the cases ($N=12$).

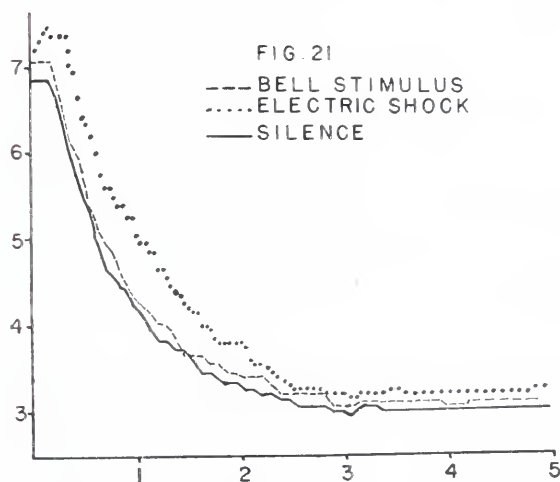
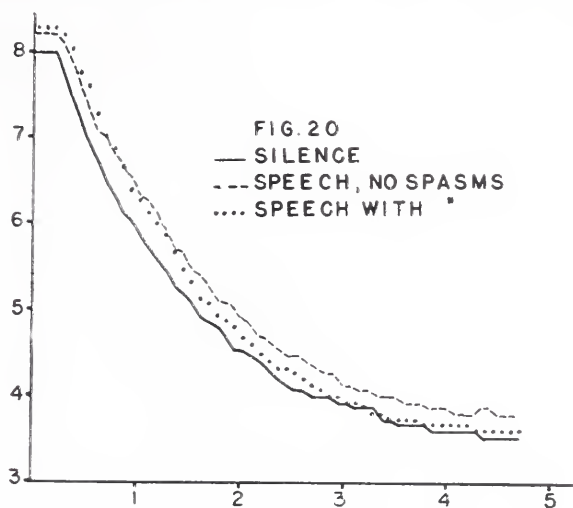
Amount of contraction during first second. The amount of contraction during the first second of constriction offers another means of comparing the differences between silence and speech (see Table XIII). Two silent periods of normal speakers

TABLE XIII. Amount of contraction in mm. during first second under conditions of silence and speech after 10 min. of adaptation

	Silence Trial A	Silence Trial B	Diff.	N
Normal speakers	2.89	2.92	+ .03	16
	Silence	Speech		
Normal speakers	2.90	2.89	-.01	10
Stutterers	2.56	2.69	+ .13	13

showed a difference of .03 mm. Speech of normal speakers had practically no influence on the amount that the pupil contracted during the first second, the difference being only .01 mm. Stutterers showed a substantial change of .13 mm. during the speech out. According to *Fisher's* tables, the chances that this difference is significant are 99 in 100.

Minimum pupillary diameter. In two successive silent periods of normal speakers ($N=23$) the average minimum pupillary



diameter was 3.063 mm. in trial A and 3.057 mm. in trial B, a difference of only .006 mm. Seventy per cent, or 16 cases, were equal; four, or 17 per cent, were less in the second trial than in the first; and three, or 13 per cent, were greater in the second trial.

The chances are 1 in 100 that this difference between the two silent periods is significant. Ten normal speakers were given two trials, one in silence and one in speech. The average minimum pupillary diameters were equal, 3.134 mm. In 11 series of one stutterer, the average minimum pupillary diameter was 3.27 mm.

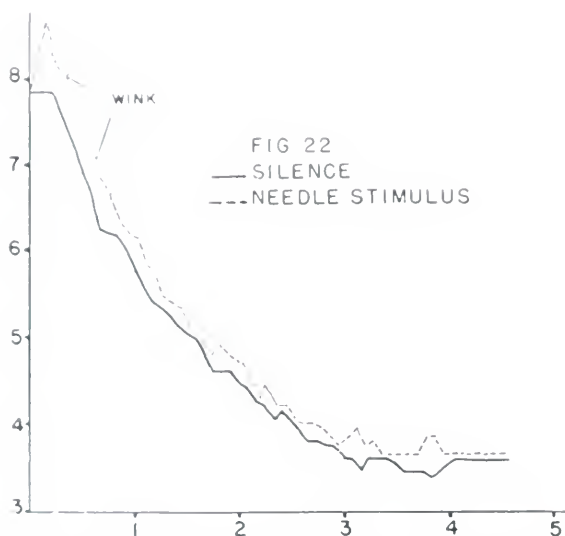


FIG. 20, 21, 22, pupillary responses to light, time in seconds represented on abscissa, diameter in mm. on ordinate. Fig. 20, responses of WD during silence, speech without spasms, and speech with spasms; dark adaptation of 10 min. Fig. 21, responses of normal speaker, EF, to light during silence, after bell stimulus and after electric shock; stimuli applied just prior to appearance of the light. Fig. 22, responses of normal speaker, WS, during silence and after a needle stimulus to the arm, applied just prior to appearance of light.

for silence and 3.35 mm. for stuttering. The chances are 57 in 100 that this difference is significant. In the series of 13 stutterers, the average minimum pupillary diameter was 3.08 for silence and 3.16 mm. for stuttering. The chances are 49 in 100 that this difference is significant. Furthermore, 85 per cent of the minimum diameters were larger during stuttering than silence.

Amount of total contraction. The 10 normal speakers just mentioned showed an average total contraction of 4.72 mm.

during silence and 4.73 mm. during speech. Ten stutterers showed an average total contraction of 4.23 mm. during silence and 4.36 mm. during stuttering and the chances are 99 in 100 that this is significant. The stutterer who was given 11 series of silence and stuttering showed an average total contraction of 4.17 mm. for silence and 4.45 mm. for stuttering. The chances are 88 in 100 that this difference is significant.

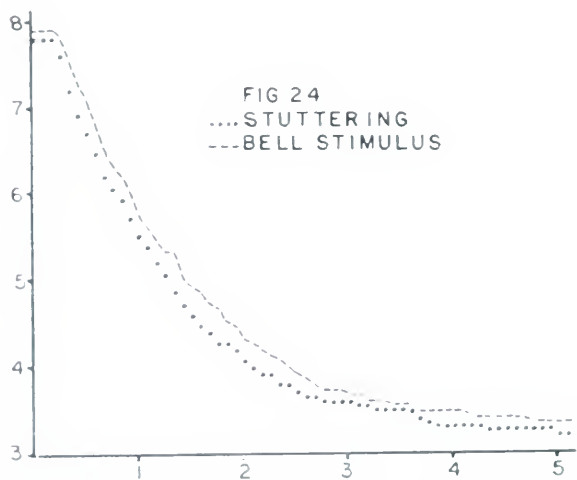
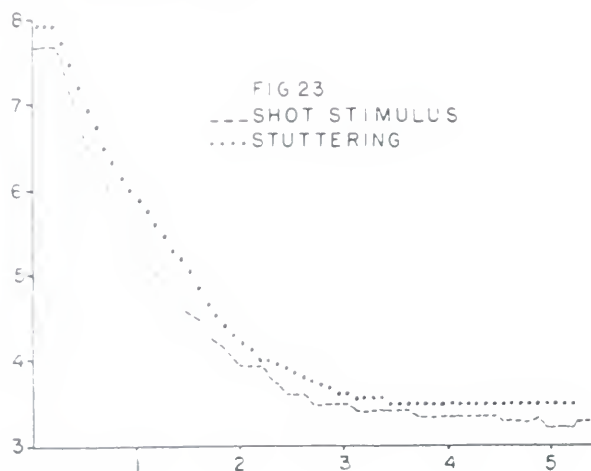
'Normal' speech of a stutterer. Fig. 20 shows the curves of contraction of a stutterer's pupil under conditions of silence, stuttering, and speech in which no spasms were noticeable. The dilated diameters were 8.00, 8.27 and 8.20 mm. respectively. Data obtained from the left eye of the same *S* showed the dilated diameters of silence, stuttering and 'normal' speech to be 8.27, 8.40 and 8.40 mm. respectively.

Effect of Extra-Stimuli on Pupillary Reflex

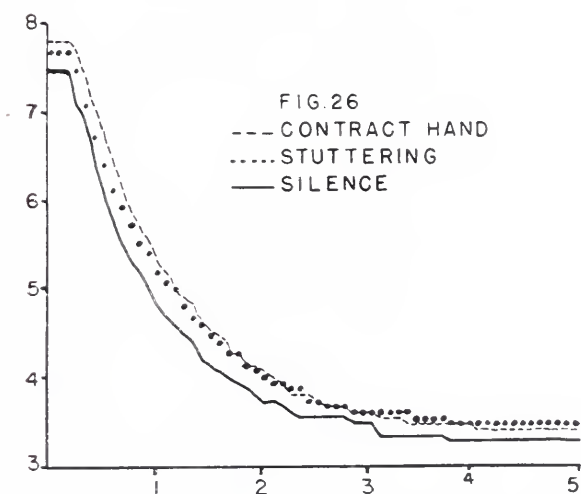
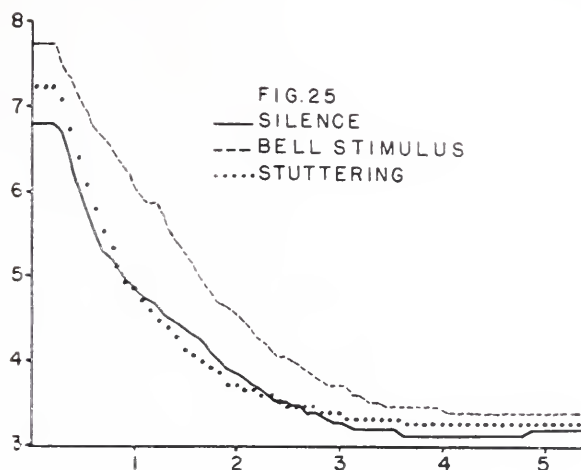
The influence of extra-stimuli (*i.e.*, stimuli accompanying the light stimulus) on the pupillary response of a normal speaker is shown in Fig. 21. The dilated diameter was 6.85 mm. during silence and 7.05 mm. after a bell was rung just prior to the light stimulus; it was 7.2 mm. after *S* was given an electric shock and the dilatation continued up to 7.45 mm., then leveled off to 7.35 mm. before its initial sharp contraction began. The latent times for the light reflex, bell response, and electric shock response were .20 sec., .25 sec., and .375 sec. A needle prick was administered to the arm of WS (Fig. 22), producing a continued enlargement even after the light stimulus appeared, from 7.83 mm. to 8.65 mm. before the pupil began to contract.

The effect of gun shot stimulus on RY (Fig. 23) was to dilate the pupil to 7.67 mm., compared with a dilated diameter of 7.93 mm. during stuttering. However, in Fig. 24, the same *S*'s pupillary response to a bell stimulus was greater than it was during stuttering. In Fig. 25, the dilated diameters after silence, stuttering and bell stimulus were 6.80, 7.23, and 7.73 mm. respectively. In Fig. 26 the dilated diameters after silence, stuttering and hand contraction were 7.45, 7.67 and 7.80 mm. respectively. These facts indicate that the extra stimulations usually produced

greater responses of the pupil than when the pupillary reflex was compared by speech blocks.



3. Asynchrony. An attempt was made to determine the effect on the pupillary response when asynchronies in the speech musculature were present during the speech act. Apparatus and technique were designed to photograph the pupillary response during speech under conditions in which factors tending to influence pupillary phenomena were reduced to a minimum.



FIGS. 23, 24, 25, 26. Pupillary responses of stutterers to light; time in seconds represented on abscissa, diameter in mm. on ordinate. Fig. 23, responses of RY during stuttering and after a shot, fired just prior to appearance of light, *S* remaining silent in latter trial. Fig. 24, responses of RY during stuttering and after a bell stimulus, *S* remaining silent in latter trial. Fig. 25, responses of WD, during silence, stuttering, and after a bell stimulus applied just prior to appearance of light. Fig. 26, responses of WD, during silence, stuttering, and after *S* had been firmly grasping a bar two seconds prior to appearance of light.

2. Study of the normal pupillary response to light showed the following:

1. The latent time averaged .237 sec., with a range of .167-.292 sec. in 41 Ss ranging in age from 18 to 35 yrs.

2. The average pupillary diameter after ten minutes of dark adaptation which followed exposure for five seconds to a light-intensity of 450 foot-candles, was 7.54 mm. for right eyes of 41 Ss. The right pupil of 28 Ss measured 7.58 mm. and the left pupil 7.50 mm. The right pupil of males was .41 mm. larger than females and the left pupil was .44 mm. larger than the females. The right and left pupils of normal speakers were larger than the pupils of stutterers, the right by .24 mm. and the left by .25 mm.

3. A slight correlation was found between size of pupil and age, $r = .52$ for 22 cases of normal speakers and $r = .39$ for 22 stutterers. But within a given age, for example 22 yrs., may be found the extremes of the distribution.

4. Pupillary diameter increased with length of period of adaptation, greatly within the first 10 seconds and more slowly thereafter. The diameter at 5 min. in most cases was smaller than the diameter at 10 min.

5. The dilated pupillary diameter was not consistently the same from day to day at the same hour. One S's diameters had a range of .40 mm. within seven successive daily measurements.

6. The pupillary diameter was large early in the morning, became smaller in the middle of the day, and became still larger at night.

7. In immediately successive pupillary responses to light within a half hour, during silence, identical diameters were obtained in 70 per cent of 20 cases.

8. Contraction time was 3.64 sec. for the right pupil and 3.51 sec. for the left.

9. The amount of contraction for the first second after initiation of constriction were 2.75 and 2.88 mm. for the right and left pupils of normal speakers. For stutterers they were 2.51 and 2.79 mm. respectively for the right and left pupils.

10. The total amounts of contraction were 4.54 and 4.38 mm. for right and left pupils of 26 Ss, with a range of 3.20–5.34 mm.

11. The average minimum diameters reached in the constriction were 3.13 and 3.10 mm. for the right and left pupils of 27 cases, with a range of 2.53–3.73 mm.

The pupillary response to light was altered during the speech act in the following directions.

1. The dilated diameter at the end of 10 minutes, photographed while normal speakers were silent and while they were speaking, averaged 7.73 mm. in both cases ($N=13$).

2. Seventeen stutterers were photographed under similar conditions. The average pupil dilated to 7.37 mm. during silence and to 7.62 mm. during stuttering. The chances are 93 in 100 that this difference is significant. One hundred per cent of stutterers showed increases in dilated diameters during stuttering while 54 per cent of normal speakers showed identical diameters and 23 per cent showed decreases.

3. One normal speaker's measurements during five series averaged an increase of .19 mm. during the speech act. This indicated that among some normal speakers the normal antagonism of the pupillary muscles is altered during speech in a manner similar to that of stutterers.

4. The contraction times for normal speakers during silence and speech were 3.58 sec. and 3.656 sec.; the contraction times of stutterers were 3.48 sec. and 3.38 sec. for silence and stuttering. The chances are 12 in 100 that the former difference is significant, compared with 69 chances in 100 that the latter difference is significant.

5. The amounts of contraction in normal speakers during the first second of constriction were 2.90 and 2.89 mm. in silence and speech; in stutterers, they were 2.59 mm. and 2.69 mm. during silence and stuttering. The chances are 99 in 100 that the latter difference is significant.

6. The minimum pupillary diameters of 23 normal speakers in two successive photographic records during silence were 3.063 and 3.057 mm.; 70 per cent of the cases were equal. Similar

diameter of 10 normal speakers during silence and speech were the same, 3.134 mm. Similar diameters of 13 stutterers during silence and speech were 3.08 and 3.16 mm, respectively. The chances are 49 in 100 that this last difference is significant and 87 per cent of the stutterers showed an increased minimum pupillary diameter during stuttering.

7. Total amounts of contraction of the pupil for 10 normal speakers averaged 4.72 and 4.73 mm. during silence and speech. Ten stutterers averaged 4.23 and 4.36 mm. during silence and stuttering. The chances are 99 in 100 that the latter difference is significant. In 11 series of one stutterer, the total amount of contraction increased from 4.17 to 4.45 mm. during stuttering. The chances are 88 in 100 that this difference is significant.

8. When no spasms were present during the stutterer's speech the dilated diameter was identical in one eye and almost identical in the other eye with the diameter observed during stuttering.

9. Administration of extra-stimuli (needle prick, shot, bell, electric shock, hand contraction) effected a greater alteration of the pupillary response than was observed during the abnormal speech of stutterers.

11. Conclusions. The dysfunctioning of neurophysiological mechanisms of the stutterer, as revealed by much research in the laboratories in the University of Iowa, is a possible source of the stutterer's speech difficulties. The results cited above now show that the delicate balance between the constrictor and dilator muscles of the pupil, which are innervated by opposing branches of the autonomic nervous system, is likewise disarranged. The normal pupillary response to light is altered consistently in dilated diameter, the various speeds and amounts of contraction, and minimum diameter, when spasms are present in the speech of the stutterer. Whether this points to a widespread dysorganization throughout the entire nervous system or whether it is the product of an emotional attitude so often present in stutterers during speech, or whether it is a product of many factors, it would be impossible to demonstrate with the information at present available.

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DYSINTEGRATION IN THE SPEECH MUSCULATURE OF STUTTERERS DURING THE PRODUCTION OF A NON-VOCAL TEMPORAL PATTERN

by

YUBA L. HUNSLEY

Introduction. This investigation proposes to test one of the hypotheses upon which the cerebral dominance theory of stuttering rests. This hypothesis as stated by Travis (5) is as follows: stutterers lack a dominant gradient of excitation sufficient to integrate the bilateral speech musculature which, when acting as a unit, must perform a pattern of movements in time. If stutterers show a marked inferiority to normal speakers in their ability to perform a pattern of movements in time with the jaws, lips, tongue, and abdomen, the hypothesis may be said to have been in part substantiated.

The task given, as will be explained in detail later, was to reproduce as exactly as possible a temporal pattern of auditory clicks. A high degree of nervous integration would be required for an individual to accomplish this with exactitude. In so far as the paired musculatures involved did act as a unit would this precision of performance be achieved. Exponents of the cerebral dominance theory believe that stutterers, due to their lack of a dominant gradient of excitation, are much less able than normal speakers to achieve this functional unity of muscular contraction. At the proper moment, it would follow that stutterers would be markedly inferior to normal speakers in following such an auditory rhythm. Such an experiment would have the additional advantage of eliminating largely, if not entirely, those factors which have been proposed by the opponents of the cerebral dominance theory to explain the difference between stutterers and non-stutterers; namely, the anxieties, dreads, and mal-emotional attitudes to which communication in speech has been conditioned.

This entire experimental set-up involved no communication, vocalization, or anything which might be classed as speech.

This experiment seeks to answer the question: are stutterers markedly inferior to normal speakers in the use of speech musculatures in a non-speech act?

The whole activity of speaking involves the movement of the lips, cheeks, jaws, tongue, soft palate and uvula, larynx, epiglottis, thorax, and diaphragm. Speech is a single function depending upon the usage of structurally and functionally dissimilar parts, each one of which is bilaterally innervated. Any one of these various musculatures when used as a functional unit provides the conditions appropriate to this experiment, and those of the jaws, lips, tongue, and abdomen were chosen for investigation.

In order for any of these component musculatures, for example the tongue, to act as a functional unit in voluntary acts, nerve impulses from the cortex cerebri must be sent to both halves of the tongue. These nerve impulses must be essentially identical in their moment of onset and in their appropriate amplitude, frequency, and duration. *Travis* (4) has shown that action current records taken simultaneously from the two masseters give evidence that these muscles are not being innervated in an identical or similar manner during stuttering. In normal speech, however, it was shown that the masseters work as a functional unit and contract at precise moments in time. The precision required in bilateral innervation of the speech musculature for normal speech is necessary for the performance of a pattern of movements in time such as that required in the present experiment.

Blackburn (1), in a study of the voluntary rhythmical movements of the diaphragm, tongue, lips, and jaws found that stutterers showed a decided inferiority to normal speakers in their ability to control movements of the mid-line speech structures, quite aside from the speech situation. *Seth* (3) duplicated the work of *Blackburn* and corroborated his conclusions. *West* (6) reported an attempt to discover a measurable factor which would clearly differentiate stutterers from normal speakers. He showed that stutterers have a significantly lower rate of repetitive volun-

movements of the jaw and eyebrow musculatures than has the normal speaker. Cross (2) made a study of the motor capacities of stutterers and normal speakers and concluded that stutterers are markedly inferior to normal speakers in bimanual activity.

II. Subjects. Twenty stutterers from the speech clinic of the State University of Iowa, 17 men and three women, were used as the experimental group. Of this group, two men were graduate students and one was a high school student. The other 17 were university undergraduates. No attempt was made to control the amount of treatment that each of the stutterers had received. The control group consisted of 20 normal speakers, including 15 men and five women. Five of this group were graduate students and the other 15 were university undergraduates. Most of the undergraduates were from a sophomore elementary psychology class. All the stutterers were familiar with experimental situations since they had been Ss in other experiments. The experimental situation was new to most of the control group, since it was their first experience of this kind.

III. Procedure. The movements of the muscle groups were recorded by means of a Marey tambour attached to a Stoelting polygraph. The recording paper passed through the machine at a constant speed of 64 mm. per second. This provided a movement pattern which was fairly easy to read. The pattern of auditory clicks was made by an aluminum disc placed on a turntable of a phonograph. On the edge of this disc were fitted lugs, spaced for the rhythm pattern to be used. Each lug was one inch long and $\frac{1}{4}$ in. wide. A strip of stiff brass contacted the lugs which provided the stimulating clicks. The pattern used was 0.1:0.1 time. The first quarter note was split into two eighth notes, thus making a pattern of four clicks. By means of a polygraph pen this stimulus pattern was objectively recorded simultaneously with the performance pattern made by S.

Movements of the lips were detected by means of a small pliable rubber bulb placed between them. The bulb was connected to the recording by means of a long rubber tube, so that a movement

of the lips was recorded by a movement of the tambour pen. Jaw movements were recorded by *S*'s biting a thick-walled rubber tube, one end of which was sealed and the other connected with the tube leading to the recording tambour. Thus when *S* opened and closed his jaws the movements were recorded. A Marey cardiograph provided an adequate means of recording tongue protrusions and withdrawals. *S* moved his tongue in and out of his mouth, taking pains to keep the tip of it against the rubber dam of the cardiograph tambour all of the time. A Summer pneumograph, placed around the body at the point of the xiphoid process, was used to record the movements of the breathing musculature. *S* was instructed to reproduce the stimulus pattern by short 'panting' movements.

One stimulus pattern was produced with one revolution of the disc. The speed of production of the pattern could thus be controlled by the speed regulator of the phonograph. Twelve different speeds, progressing from slow to fast, were used. This insured an adequate test of the influence of speed on production of performance patterns. The speeds used were as follows: 30.7, 40.0, 51.3, 60.0, 65.2, 69.8, 75.1, 80.0, 83.5, 85.4, 89.3, and 91.3 revolutions per minute. The constancy of the speeds was checked in terms of average duration of the stimulus pattern. The average duration in seconds for 51.3 revolutions per minute was $1.4625 \pm .0228$, and for 85.4 revolutions per minute it was $.896 \pm .00375$. The minuteness of the standard deviations indicates the constancy of the stimulus pattern.

For each *S* the recordings were as follows: jaw movements, lip movements, tongue movements, and breath movements. *S* was seated so that he was unable to see the apparatus and *E*. No information was given to him concerning the actual purpose of the experiment. He was instructed in the use of each particular piece of apparatus and any questions that arose concerning the manipulation of it were answered. *S* then listened to the auditory stimulus pattern for a short time. The stimulation apparatus then was stopped and *S* given these instructions:

"I want you to reproduce this rhythmic pattern as nearly perfectly as you can, following both the pattern and the speed. Try it."

A short practice period was given at this point and further instructions were necessary in a few cases to make sure that *S* understood what was wanted. *S* then was given the following instructions:

Repeat the pattern as fast as possible after I tell you to begin. Start at the beginning of the pattern. Repeat the pattern *once* and *once only*. This is the pattern: (the pattern is illustrated with taps on the table). Start when I say: 'begin.' Ready. 'begin.'

The polygraph was started at the word 'ready.' The signal of 'ready-begin' was given before each of the three trials at each speed.

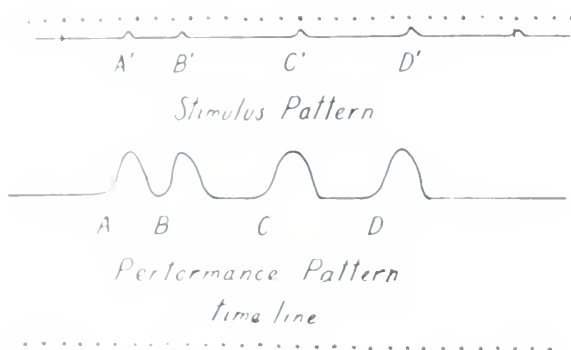


FIG. 1. Record of performance pattern.

In order to make a quantitative analysis of the performance pattern at each speed for each muscle group tested, and in order to make a quantitative comparison between stutters and normal speakers it was necessary to develop a method of scoring the performance patterns in which would be considered the four movements in the pattern and the rate of performance. The method of scoring (Fig. 1) consisted in finding the ratios between the first (AB) and second (BC), and between the second (BC) and third (CD) time intervals of the performance pattern, each interval being measured as millimeters. The difference between each ratio and its corresponding ratio in the stimulus pattern (A' to B') was found, and the two values thus obtained were summed without regard to sign. The formula which expresses the above computation is therefore

$$\left(\frac{AB}{BC} - \frac{A'B'}{B'C'}\right) + \left(\frac{BC}{CD} - \frac{B'C'}{C'D'}\right).$$

The above method of scoring provided an accurate determination of the manner in which the rhythm of the performance pattern (*i.e.*, the relations of component movements to each other) corresponded to the rhythm of the stimulus pattern. However, since *S* could have given a performance pattern which corresponded exactly in the time relations of its component movements to those of the stimulus pattern and yet have performed the pattern much more slowly than the speed of the objective pattern required, it was necessary to multiply the value ascertained from the above formula by the ratio between the duration of the stimulus pattern (*A'D'*) and the duration of the performance pattern (*AD*). The complete formula was, therefore, the preceding formula multiplied by the ratio of the two durations or

$$\left[\left(\frac{AB}{BC} - \frac{A'B'}{B'C'}\right) + \left(\frac{BC}{CD} - \frac{B'C'}{C'D'}\right)\right] \frac{AD}{A'D'}.$$

The resultant value is thus a measure of both speed and accuracy factors.

Interval ratios were especially useful in that the amount of performance error was weighted according to the specific interval involved. The use of these ratios permitted a given deviation in any part of the pattern, whether between the first and second time interval or between the second and third time interval, to make its appropriate effect on the final score.

In order to determine the accuracy of the scoring of the records, 144 individual performance patterns were measured and scored a second time. The values thus obtained were correlated with the corresponding values of the first scoring. The resultant reliability coefficient was $.97 \pm .003$.

The scores of the trials ranged from zero to 100, zero being perfect and 100 or over a failure. The score reached 100 or over when (1) the time intervals between any or all of the four movements were either too long or too short in comparison with the stimulus pattern, or (2) the performance pattern consisted of more or less than four movements.

because of the possibility of chance failure or chance perfection entering into the production of the performance, Ss were required to give three separate reproductions of the stimulus pattern at each speed by each of the four muscle groups listed.

As a result of a preliminary experiment, three such reproductions were deemed sufficient to get an adequate sampling of S's performance at each speed. There was a coefficient of correlation of $.87 \pm .05$ between the average score of the first three trials and the average score of five trials; there was a correlation of $.90 \pm .04$ between the best score of the first three trials and the best score of the five trials.

Correlations between the scores of the first and third trials at each speed were compared in an attempt to find how consistent the individual was in performing any given speed from time to time. The coefficients of reliability determined in this manner for each of the four musculature groups were as follows:

	r	P.E.
Ways	.41	.03
Ups	.36	.03
Tongue	.32	.04
Breathing	.46	.03

These are minimum correlations. The true correlations probably are somewhat higher, for the methods of measuring and scoring were relatively fine. These reliability measures do not measure how closely the first performance pattern conforms to the third performance pattern, but they do show the amount of disagreement between the stimulus pattern and the first performance pattern as compared with the amount of disagreement between the stimulus pattern and the first performance pattern as compared with the amount of disagreement between the stimulus pattern and the third performance pattern. In other words the reliability coefficients show how consistently S in his performance conforms to the stimulus pattern.

Reliability coefficients also were computed between the first and second, between the second and third, and between the first and third approximations to the stimulus pattern. These were based on a smaller number of Ss and the values thus found approximated the coefficients for all Ss on the first and third trials.

Since the low reliability coefficients show that any one performance is not a reliable index of how well an *S* could perform the pattern, the average score of the three trials, and the optimal or best score were used in computing the difference between normal speakers and stutterers.

IV. Results: quantitative data. After all the records had been obtained, they were measured and scored according to the procedure already outlined. The results thus obtained were tabulated according to (1) the average score of the three trials made by each *S* at each speed, (2) the optimal score made by each *S* at each speed, and (3) the rank order of the best performance of each *S* at each speed, based upon the average of three trials. The data for each speed were then converted into group averages. The SDs of the distribution were computed and the CRs of the difference between the stutterers and normal speakers ascertained. In Tables I-IV inclusive are found the results as given separately for the movements of the jaws, lips, tongue, and breathing mechanism. These data show that at every speed in each muscle group, the non-stutterers' performance, with one exception, was better than the stutterers' performance. This one exception was at 89.3 r.p.m., on performance with the tongue musculature. Both groups were nearing the upper limit of scores. The CRs show a statistically significant difference between the two groups.

In order that the findings may be more clearly presented, the data are shown graphically in Fig. 2. For both groups there is a constant increase in difficulty of performance as the speed of the stimulus pattern becomes greater, as shown by the increase in size of scores. These data also show that as the speed increases the differences between the two groups decrease. This may be evident because both groups are approaching the upper limit of performance capacity. These findings hold true for the performances of the jaws, lips, tongue, and breathing mechanism.

It will be noted also that, in general, stutterers gave a better performance at 40.0 than at 30.7 r.p.m. When the speed was slower than 30.7 r.p.m., the stutterers either were unable to perform or gave a very poor performance.

The optimal score made by each *S* at each speed for each

TABLE IV. *A comparison of normal speakers and stutterers in regard to breathing movements*

r.p.m.	Controls (N=20)			Stutterers (N=20)			Diff. SD Diff.	Chances in 100
	Av. score	SD	Rank order	Av. score	SD	Rank order		
30.7	43.55	25.3	3.8	72.00	31.6	4.9	3.16	100
40.0	40.90	26.8	3.9	74.00	30.9	4.7	3.72	100
51.3	42.35	30.7	4.0	75.20	26.0	4.8	3.65	100
60.0	62.30	30.0	6.4	70.75	29.2	4.4	0.91	82
65.2	55.70	27.6	5.3	81.25	23.1	5.7	3.18	100
69.8	68.00	32.2	7.2	84.40	21.8	6.7	1.88	97
75.1	66.25	30.6	6.5	82.15	25.4	6.1	1.79	96
80.0	73.60	27.5	8.0	83.25	23.0	6.9	1.21	88
83.5	68.80	22.7	7.8	96.00	9.3	8.9	5.00	100
85.4	74.15	23.8	8.2	91.90	6.1	7.8	3.05	100
89.3	80.00	25.2	8.8	90.80	17.2	8.6	1.59	94
91.3	74.70	29.4	7.9	94.70	9.9	8.4	3.00	100

musculature gave the same general picture as did the average score for each speed. This was to be expected, since the optimal score accounted for a third of the average score for that particular speed. The CRs were computed in the same manner as for the average score. They presented the same general picture. Because of the great similarity of results these data are omitted.

These tabulations and graphs show that (1) stutterers are not able to perform a pattern of movements in time as well as normal speakers, and (2) both stutterers and normal speakers perform less accurately when the rate of movement increases. The results of this phase of the experiment (Tables I-IV and Fig. 2) demonstrate that in the performance of a pattern of movements in time, stutterers are distinguished from normals to a degree which is statistically significant.

When the investigation was begun it was felt that stutterers and normal speakers would not be differentiated by the temporal pattern at slow speeds, but that, after a certain speed had been reached, normal speakers would do much better than stutterers. This was not the case, since stutterers and normal speakers are differentiated at all speeds. Yet, in order to determine whether the performance of stutterers did tend to break down at a slower speed than did the normals, the data were treated by the procedure of ranking speeds in order of best performance. This

procedure also provides a measure of the effect of increasing the speed of the stimulus pattern on the performance of both stutters and normal speakers.

The rank order of the various speeds was tabulated for each

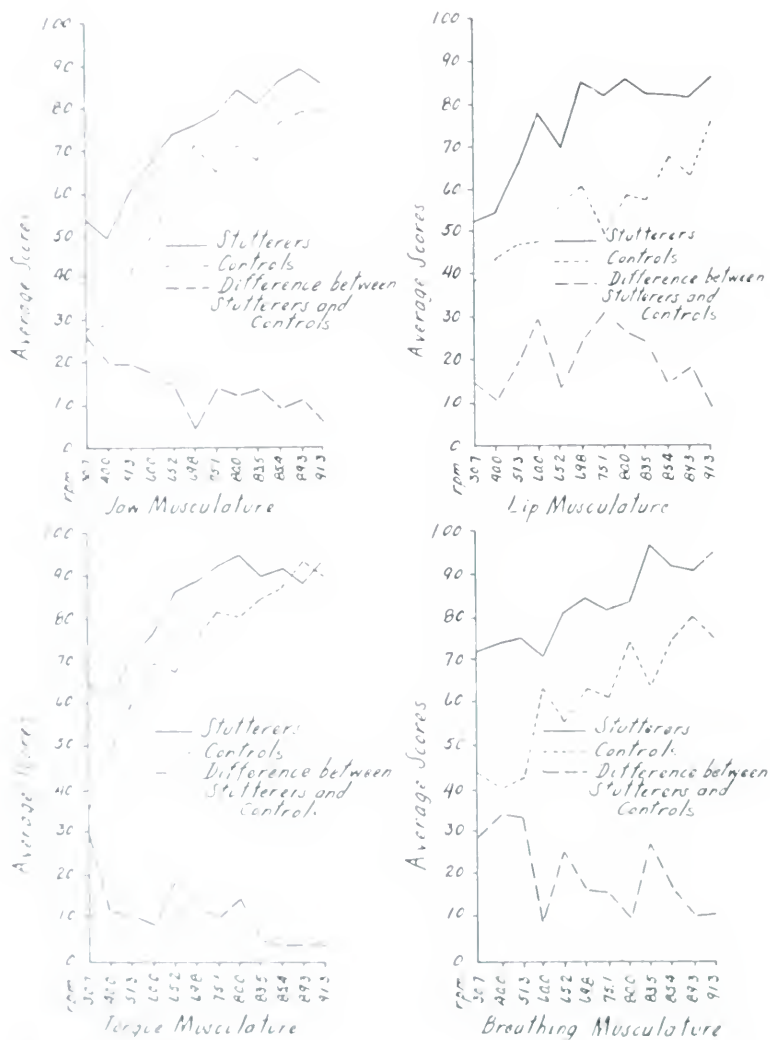


Fig. 2. Group average of average score of the three trials made by each S at each speed.

individual. Then the rankings at each speed were averaged. This provided an average rank order for the various speeds of both the stutterers and controls. These average rankings are presented in Tables I-IV inclusive.

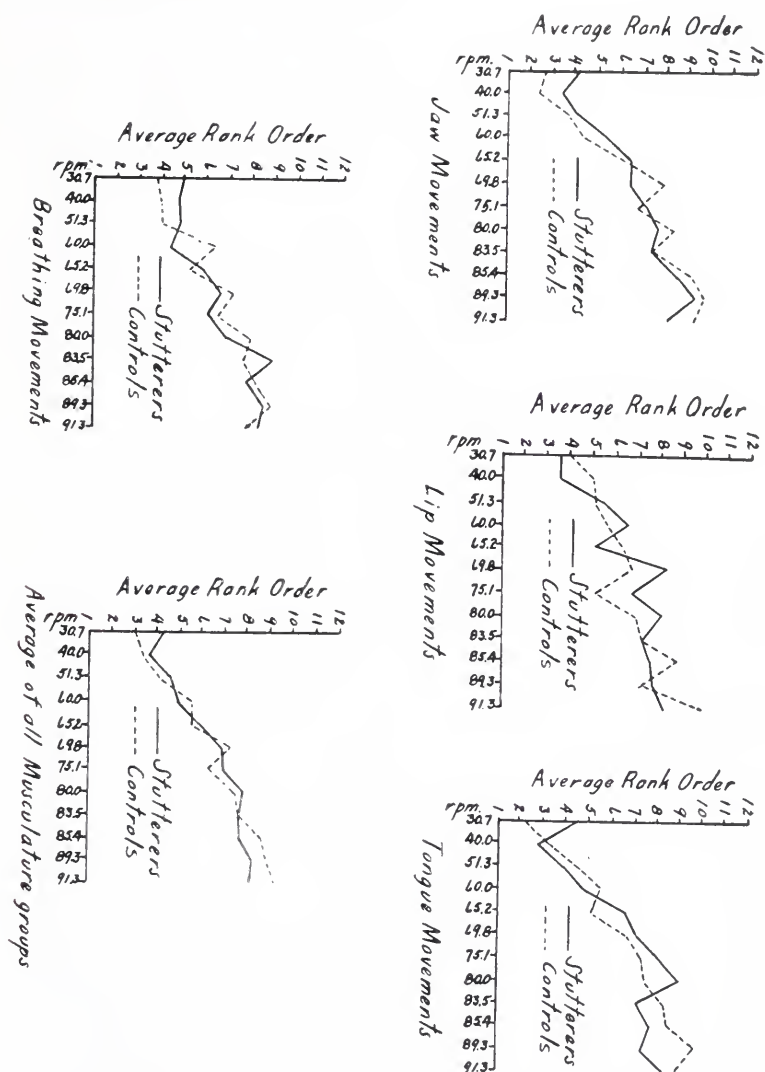


FIG. 3. Average rank order of best performance for each speed for both groups.

The graphs in Fig. 3 show that (1) as the speed increases, the amount of performance error increases for both stutterers and normal speakers; (2) speed has very similar effects on both groups, namely, accuracy of performance decreases as speed increases; (3) the performance of the stutterers did not tend to break down at a slower speed than did the normal speakers, but there was an increasing difficulty of performance for both groups. Therefore, these tabulations and graphs show that the speed factor was not the element that differentiated stutterers from normal speakers.

Qualitative data. Although the major contribution of this study may be the discovery that normal speakers and stutterers are quantitatively differentiated in their performance of a temporal movement pattern with the speech musculature, so many qualitative differences occurred that it was felt appropriate to include them as a part of the report.

In general it may be said that recordings made by stutterers were very irregular when compared to those of normal speakers. Upon analysis of these irregularities, it was found that they could be classified in terms of the following major categories: (1) breaks (*i.e.*, failure at a certain speed as indicated by an average score of 100 at that speed); (2) reversals of temporal intervals of the movement pattern; (3) too many movements (*i.e.*, more than four movements) in the performance pattern; (4) too few movements (*i.e.*, three movements or less) in the performance pattern; (5) small movements superimposed on the large movements of the performance pattern; and (6) blocks, both tonic and clonic, in the performance pattern. Examples from each of these classes of irregularities are shown in Figs. 4-9 inclusive. These irregularities, classified under the various categories, were tabulated according to the number of occurrences at each speed. The total number of occurrences for each category was found and the percentage for the two groups based upon a possible 2,880 occurrences was ascertained. The results are given in Table A; they are graphically shown in Fig. 10.

It will be noted that in all but one category, namely, 'too few movements' the total number of occurrences and percentage of

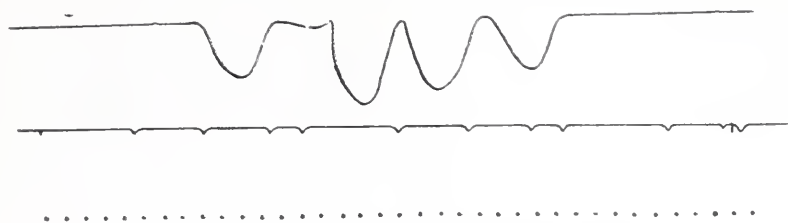


FIG. 4. Type 1: Failure of performance pattern.

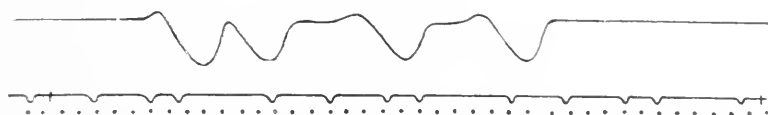


FIG. 5. Type 2: Reversal of temporal intervals on the performance pattern.

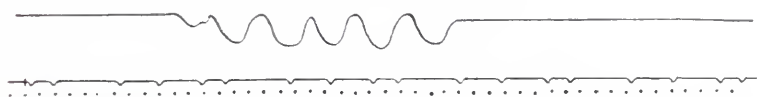


FIG. 6. Type 3: Too many movements in the performance pattern.

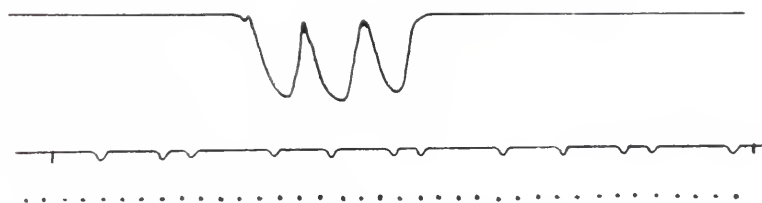


FIG. 7. Type 4: Too few movements in the performance pattern.

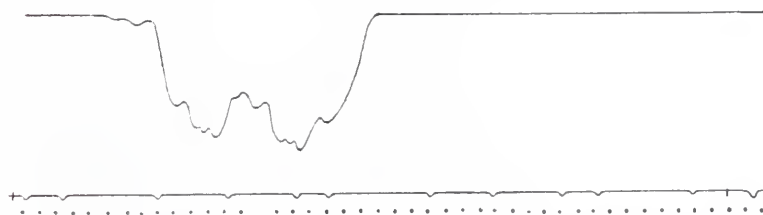


FIG. 8. Type 5: Small movements superimposed on the large movements of the performance pattern.

TABLE V. Qualitative differences in the performance patterns of normal speakers and stutterers

	No. of breaks		No. of pattern reversals		No. of too many movements		No. of too few movements		No. of small movements		No. of block	
	C	S	C	S	C	S	C	S	C	S	C	S
Total	158	319	39	180	232	458	368	334	32	238	9	526
Percent of occurrence	16.4	33.2	1.3	6.2	8.0	15.9	12.8	11.6	1.1	8.3	0.3	18.3
Jaw	29	40	2	44	89	116	108	72	24	8	3	28
Eye	17	60	1	52	41	124	71	105	3	56	1	109
Forearm	56	99	20	47	84	176	138	111	5	30	4	123
Wrist	56	120	16	37	18	42	51	46	0	144	1	266

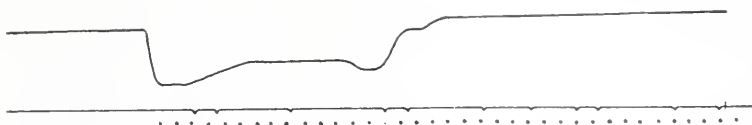


Fig. 9. Type 6: Block of the performance pattern.

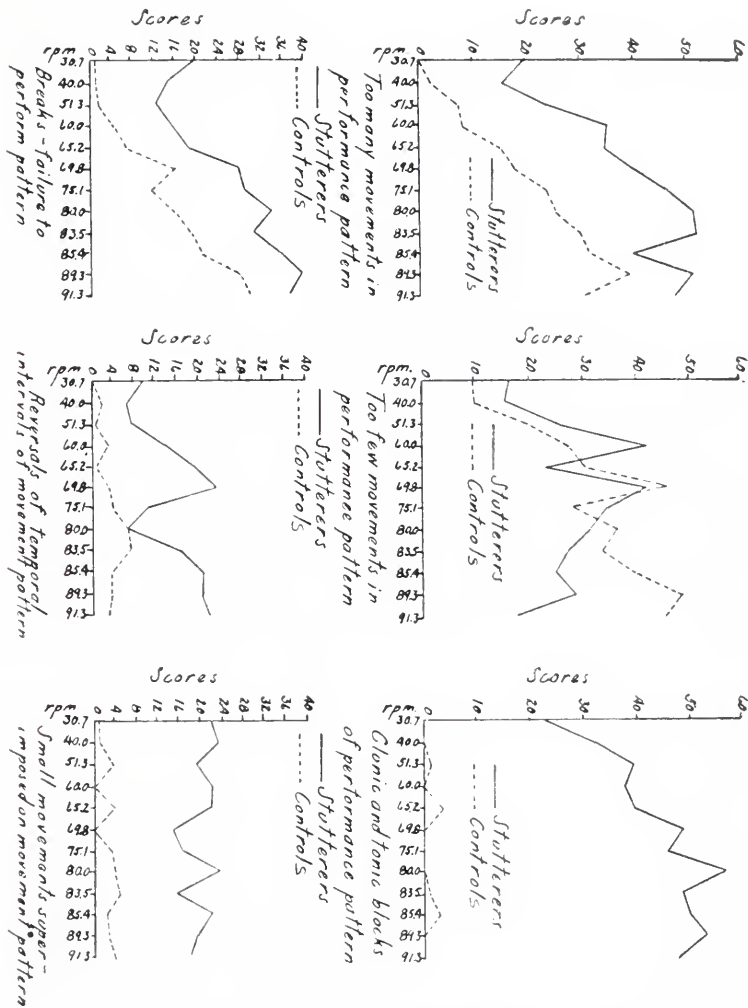


Fig. 10. Qualitative differences in the performance pattern of normal speakers and stutterers at each speed.

occurrences of the irregularities were much greater for the stuttering than for the non-stuttering group. The total number of irregularities in the category of 'too few movements' was nearly equal for the two groups, non-stutterers slightly surpassing the stutterers.

In general, both stutterers and normal speakers, in the first three categories listed, showed an increase in the number of irregularities with an increase in the rate of movement. For all speeds, stutterers had a greater number of irregularities than did normal speakers. In the category of 'too few movements,' stutterers and normal speakers closely resembled each other, normal speakers having a slightly greater number of irregularities. In both groups there was an increasing number of irregularities with the increasing rate of movements. Stutterers presented a greater frequency of the incidence of small movements superimposed upon larger movements of the performance pattern. The number of occurrences of this irregularity does not increase with the increase in the rate of movement, but in both groups, the number of occurrences remains fairly constant. Stutterers greatly exceeded the normal speakers on the number of blocks. Eighteen of the 20 stutterers and only four of the 20 normal speakers presented this irregularity. The number of blocks of the stutterers increased with the increase of movements.

The results of this phase of the experiment as given in Table V and Fig. 10, demonstrate that in the performance of a pattern of movements in time, stutterers are qualitatively inferior to normal speakers.

V. Summary. This experiment sought to answer the question: are stutterers inferior to normal speakers in the use of speech musculature in a non-speech act?

From the various bilaterally innervated musculatures involved in speech, those of the jaws, lips, tongue, and breathing were selected for study. Twenty stutterers and 20 normal speakers were required to reproduce, with each of the above muscle groups in turn, a temporal pattern of clicks from an auditory stimulation apparatus.

The stimulus pattern was given at 12 different speeds; the

method of scoring provided a measure of both the speed and accuracy factors involved. The correspondence of the performance pattern to the stimulus pattern was measured, and statistically significant differences between the stuttering and normal speaking groups were found. The average rank order of the best performance for the various speeds showed that the speed factor was not the element that differentiated stutterers from normal speakers.

Many qualitative differentiae occurred between the records of stutterers and normal speakers. These were classified in the following categories: (1) breaks, *i.e.*, failure of performance at a certain speed; (2) reversals of the temporal intervals in the movement pattern; (3) too many movements in the performance pattern; (4) too few movements in the performance pattern; (5) small movements superimposed on the large movements of the performance pattern; and (6) tonic and clonic blocks of the performance pattern. An analysis of these irregularities demonstrated that stutterers are qualitatively distinguished in type of performance from normal speakers.

Stutterers were inferior to normal speakers in their ability to perform a silent pattern of movements in time with the speech musculature. Therefore the hypothesis upon which rests the cerebral dominance theory of stuttering, namely, that stutterers lack a dominant gradient sufficient to integrate the bilateral speech musculature (which, when acting as a unit, must perform a pattern of movements in time), is in part substantiated.

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AN ANALYSIS OF ASSOCIATIVE AND PREDISPOSING FACTORS IN THE SYMPTOMATOLOGY OF STUTTERING

by

ALONZO MORLEY

I. Introduction. In recent years there have been many laboratory investigations of stuttering. The three physiological systems used in the speaking act, the respiratory, articulatory and phonative, have been investigated in both normal speakers and stutterers, and comparisons have been made and conclusions drawn in regard to certain aspects of the nature of stuttering. It has been demonstrated that the stutterer differs from the normal speaker in various measures of the physiological functions of the three systems mentioned above. He exhibits mainly an apparent lack of muscular co-ordination necessary to produce synergic functioning of these physiological units.

In general two lines of investigation have been followed: (1) the determination of abnormalities that appear in the functioning of the three systems; (2) the determination of variability in the various measures of function of these systems in which wide variability from the mean of the normal speaker has been taken as an indication of dysintegration.

Older than the history of these objective measures are certain observations concerning the psychic nature of stuttering. The stutterer himself, and laymen who have observed him, have been struck with the unstable nature of the malady in regard to the time, place and circumstances of its appearance. Among the things which have been noted are the following: actors who stutter almost continuously in ordinary conversation are able to play parts on the stage with sureness and abandon; stutterers rarely stutter when they sing; the stutterer has little or no difficulty when he is alone; certain words and sounds are more diffi-

cult than others for stutterers; and stutterers have less or no difficulty when someone else reads with them.

One purpose of the present study was to bring together the two areas presented above, *i.e.*, analyses and measurements of the functioning of the three physiological systems in stuttering, and observations of the manifest variability of the disorder in varying speaking situations. One aim was, then, to answer the following question: what changes in the frequency of appearance of abnormalities, and what variability of certain measures of physiological function, are the result of changes in the situation in which the stutterer uses his speaking mechanism?

A second purpose of the study was to attempt to find an explanation for the differences that exist between the normal speaker and the stutterer in measures of physiological function. If these measures were found to vary from situation to situation in the stutterer then the aim was to discover the manner in which these changes in function are related to the phenomena of stuttering. Put in the form of a question this problem would be: are changes in measures of physiological function occurring in the stutterer expressions of the stuttering spasm itself, or are these changes the reactions of functioning physiological systems to stuttering?

II. Apparatus and procedure. This study involved an investigation of three physiological processes under eight experimental conditions. The three processes were: movements of the eyes in reading, breathing, and the action of the masseter muscles in articulation. The eight experimental conditions were silent reading and speaking situations.

It was desirable to keep the spoken content of the situations as nearly alike as possible in vocabulary, style, subject matter, and familiarity to *S.* To accomplish this the material for each of the five situations used was from the same source, a chapter of easy prose in *Crawford's "Technique of Research in Education."* The entire book is written in an easy, free-flowing style, and this chapter was particularly free from unfamiliar words and technical ideas. It consisted of good common sense advice on the technique of obtaining interviews in gathering data for educational research.

Two of the techniques of investigation, eye-movement and action current recording, used expensive photographic film. For that reason the situations were held to the minimum length compatible with obtaining a fair sample of performance.

With these experimental considerations and limitations in mind the following situations, using material from the above source, were decided upon: (1) silent reading of 75 words; (2) ordinary oral reading of 64 words; (3) relaxed oral reading of 59 words; (4) reading 56 words orally with *E*; (5) reading of 65 words while alone.

Situations using other material were included. (6) Reading difficult sounds orally—pre-determined difficult sounds were used in a sentence or two which made from two to three lines on the stimulus card of the oculo-photometer, for example, "The large, lazy, leather-lunged lout lunged low and laughed lots louder than Lilly Long, the lather's lame lady." For the eye-movement study this situation was too short. For breathing and action current recording longer selections similarly composed were used. (7) Reading orally semi-memorized poetry, 50 words—eight lines of *Robert W. Service's* poem, "The Shooting of Dan McGrew," were used. This situation proved unsatisfactory due to variation in the degree of memorization achieved. In an attempt to eliminate this factor in the breathing experiment, oral reading of familiar poetry was tried. This also proved unsatisfactory and the situation was not used in the action current experiment. (8) Speaking propositionally—*Ss* spoke for approximately one minute. This situation was not used in the eye-movement experiment.

It was desirable to keep the physical conditions of the experiments as nearly constant as possible, to avoid variations in *Ss* due to the passage of time and effects of clinical therapy. Accordingly the entire series of situations was given in each experiment with one setting of the recording apparatus. A period of time elapsed between the three general experiments. Eye-movements were taken in Oct. and Nov., 1934, breathing in March, 1935, and the action currents in April and May, 1935.

In all situations but reading while alone, *E* was the only

audience with the exception that during the recording of the eye-movements of six Ss, one other person was present. For recording eye-movements a special eye-camera known as the oculo-photometer (15) was used. A special head holder was devised to eliminate head movements. The recording was done on Eastman panchromatic 35 mm. film; the speed of the film through the motor driven camera was 12.7 mm. per sec. During the recording of eye-movements *S* was asked to look at an X in the center of a card in the holder of the camera. The beams of light reflected from the corneas of the eyes were adjusted, and the lights were brought into sharp focus on the film. *S* then was asked to read some material explaining eye-movements which was on this focusing card. While he did this his eye-movements were observed and any needed adjustments of the camera were made. Focus and position of beams on the film were checked at the beginning of each situation. With the exception of one *S* there was no apparent emotional reaction to the recording of eye-movements.

Records were taken in the following order with instructions as indicated:

Silent reading. Instructions: "The first thing that I want you to do is to read a card which is below this card that you have just read and which I want you to start reading as soon as I raise this first card. Read it silently in your ordinary manner of silent reading. When you are through reading close your eyes as a signal to me that you have finished." Camera was started and records made.

Ordinary oral reading. Instructions: "I want you to read this next card aloud. Read it as you would read aloud ordinarily."

Relaxed oral reading. Instructions: "This time I want you to read in as easy a manner as you possibly can. If you have learned a pattern which makes your speech easier I want you to use it. If not I want you to read in as relaxed a manner as possible. Take all the time that you need."

Reading orally with E. Instructions: "This time you and I are going to read together. I shall read along with you from this copy that I have. Let us try the first line." (The line was read.)

Reading orally while alone. Instructions: "This time I am going to let you take your own picture. I shall leave the room and go far enough away so as not to be able to hear you. No one will be able to hear you. I shall focus the lights so that we may get a good sharp record. Now I want you to put your hand on this switch. (Hand of *S* was directed to the switch.) Keep it there during the time that the record is being taken so that you will not move. Try the switch. Push it down. Up. You see that it starts the motor. All is ready now. Here is the card. When I am out of the room, start the camera

and read the card.⁴⁰ *E* retired and did not return until ample time had been allowed for the recording.

Reading orally predetermined difficult sounds. Instructions: "What sounds do you have the most difficulty with?" *S* would list two or three. "Well, let's try this. Please read the card."

Reading orally semi-memorized poetry. Instructions: "Do you know the 'Shootin' of Dan McGrew'?" Well, here are a few lines of it. Read it over a few times until you get these lines well in mind. You will have the card before you all of the time during which we take the record, but I want you to become thoroughly familiar with it before we take a picture. Tell me when you think that you have it reasonably well memorized." The record was taken after *S* informed *E* that he had the short passage memorized.

Speaking propositionally. Instructions: "This time I want you to talk for one minute about something that you are interested in—your school work, your hobbies, or perhaps something about your home town."

The apparatus for recording breathing consisted of a large stationary kymograph and two Marey tambours connected by heavy-walled rubber tubing to two Harvard pneumographs, one of which was placed around the thorax at the level of the arm pits, and one around the abdomen at the level of the umbilicus. A magnetic signal marker was used to indicate the overt spasms of the stutterer as the records were taken. A Jaquet chronometer was used to record time in intervals of $\frac{1}{5}$ sec.

For the breathing records male *Ss* removed all clothing and female *Ss* any heavy outer clothing above the waist.

An attempt was made to get a record of at least 20 complete respiratory cycles for each situation. This was not always possible. In the analysis no record of less than 15 complete cycles was used. For the entire group there were only two records used in the quantitative computations with less than 18 complete cycles.

The eight situations outlined above were used. It was necessary to record for longer periods of time than in the eye-movement and action current experiments in order to get the required number of respiratory cycles. *Ss* were given the book and asked to read the selections until a sufficient number of breathing cycles were recorded. The order of experimental situations was: ordinary oral reading, silent reading, relaxed oral reading, reading with *E*, reading orally while alone, reading difficult sounds, reading familiar poetry and speaking propositionally.

In analyzing the breathing records, *Fossler's* (7) technique

was employed to measure the amplitude of inspiration and expiration and the duration of inspiration and expiration of curves made by the tambours connected to the pneumograph around the thorax. One modification of this method was made. After correction for the arc of the tambour lever as outlined by *Fossler* was provided for, the measuring points were punched through the paper on the base line with a short metal stylus. The record was then passed over an illuminated reading box. The corrected durations of the breathing curves were obtained by measuring the distances between the small points of light on the record.

For studying the movements of the masseter muscles, two matched non-interfering amplifier-oscillograph units were used to record action currents (20). A signal circuit was used to signal the recognition of an overt spasm. This appeared on the record in the form of a small but definite deflection of the signal line. The film was driven at a constant speed of 4.8 cm. per second. The electrodes placed on the muscle were made of thin brass strips covered with Canton flannel saturated with concentrated saline solution. One pair of these electrodes was placed over the right masseter muscle and the other over the left masseter muscle. The distance between the two brass strips for each electrode was approximately one cm. The electrodes were carefully placed on the muscles to insure accurate recording. Time intervals of $1/25$ sec. were produced by a low-frequency oscillator. All recording was done on Eastman No. 1 35 mm. sensitized paper. Six of the eight situations outlined in the eye-movement experiment were included in this part of the study. They were given in the following order: ordinary oral reading, silent reading, oral reading of difficult sounds, reading orally with *E* and speaking propositionally. The instructions used in the eye-movement and breathing experiments were given to Ss in this experiment.

III. Subjects. Ss for the experiments in this study were stutterers enrolled in the speech clinic at the State University of Iowa. For the eye-movement experiment 21 white, male stutterers ranging in age from 18 to 29 yrs. and four white female

stutterers ranging in age from 17 to 29 yrs. were used. A group drawn from the stutterers was used for the breathing experiment. It consisted of 11 white male stutterers ranging in age from 19 to 33 yrs. and five female stutterers ranging in age from 17 to 22 yrs. For the action current experiment a group consisting of eight white male stutterers ranging in age from 18 to 23 yrs. and two white female stutterers of 17 and 22 yrs. were used. Of the 16 stutterers used in the breathing experiment, eight had been used in the eye-movement series. Of the 10 stutterers used in the action current experiment six had been used in the breathing experiment and four in both the eye-movement and breathing experiments. All stutterers were well adjusted to the experimental situations and were otherwise typical of cases commonly encountered in speech clinics.

IV. Results.

Eye-Movements

The analysis of eye-movement records consisted of measuring the number of fixations per line, duration of fixations, reading time per line, and number of regressions per line. The mean, SD, and SE_m were computed for each of these four measures of eye activity.

A small projection screen, consisting of a sheet of white paper laid off in square centimeters, was made. Then on the emulsion side of a piece of clear film a one cm. square was very carefully drawn with a pin-point. A film projector was used to superpose this square on the screen. The magnification was adjusted until the square on the film covered 100 sq. cm. on the screen, thus enlarging the square on the film 10 times. The records of eye-movements were then projected on the screen and the measurements were made directly from the lines on the screen. The distance between two lines on the screen represented a distance of one mm. on the film. By this method estimates in .1 mm. were made where the individual eye-movement did not fall exactly on a line. All measures were rechecked and errors corrected.

After mean duration of fixation and mean reading time per

line were computed in terms of mm., the values were converted to ms.

In the experimental situation, which in the case of the eye-movement experiment consisted entirely of reading situations, some of the Ss did not stutter. This fact was noted at the time the record was taken. When the computations had been made the Ss were divided into two groups. The non-affected group consists of those stutterers in whom the potentiality for stuttering was not realized during the testing situation. The affected group consists of those stutterers in whom the potentiality for stuttering was expressed in actual overt spasms. Statistically treated differences between the groups will be presented.

Number of fixations per line. In Table I appear the records of the two groups analyzed as to mean fixations per line. The value for silent reading may be considered as the natural response of the eyes in reading when no combined action with the voice is demanded. Comparison of the groups in this situation gives a basis for evaluating the effect of stuttering in the oral reading situations.

Inspection of the table shows that the values for the groups are approximately the same in the silent reading situation. In oral reading situations, values for the non-affected group are relatively much more constant from situation to situation than are the values for the affected group. The values of the latter group tend to vary widely from situation to situation. In the situation in which the Ss read with *E* the value was lower for the affected than for the non-affected group. Another interesting point about this particular situation is that the value for the non-affected group was next to the highest in the series, while that of the affected group was next to the lowest for the six oral reading situations. Both groups have the highest scores in the situation where they were asked to do relaxed reading. The groups are approximately equal in silent reading, reading semi-memorized poetry, and reading alone.

While the statistical reliability of results from any one situation is not high, the values for silent reading, reading with *E*, reading alone, and reading semi-memorized poetry show no dif-

TABLE I. *Mean fixations per line, of non-affected and affected groups of stutters, in seven situations*

Group	Silent reading		Oral Reading Situations								Poetry			
	Mean	SD	Ordinary		Relaxed		With E		Alone		Difficult sounds		Mean	SD
Affected	7.71	2.21	12.32	3.75	14.17	5.92	10.66	1.87	10.85	2.08	10.84	4.21	8.79	2.02
Non-affected	7.78	1.81	9.80	1.44	11.26	1.56	11.21	1.18	10.78	1.30	7.59	2.38	8.75	1.80
Diff. and PE _{diff.}	.07±.82		2.25±1.06		2.91±1.58		—, .55±.62		.07±.68		3.25±1.32		.04±.81	
Chances in 100 that true difference is greater than zero	52		99		96		80		54		99		50	

TABLE II. Mean duration of fixations of affected and non-affected groups of stutterers in seven situations (values in ms.)

Group	Silent reading		Ordinary		Relaxed		With E		Alone		Difficult sounds		Poetry	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affected	206	23	384	129	398	160	286	47	304	22	376	91	305	91
Non-affected	181	31	221	27	233	33	233	23	245	35	254	65	229	26
Diff. and P.E. _{diff}	25±12		163±36		165±43		53±14		59±13		122±79		76±25	
Chances in 100 that true difference is greater than zero	98		100		100		100		100		85		100	

TABLE III. Standard deviation of mean duration of fixation of affected and non-affected groups of scutters in seven situations (values in ms.)

Group	Silent reading		Ordinary		Relaxed		With E		Alone		Difficult sounds		Poetry	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affected	115	49	362	346	375	279	169	40	200	101	293	146	217	113
Non-affected	62	10	103	21	124	31	117	26	124	38	134	82	114	31
Diff. and PE _{Diff.}	53±16		259±90		251±63		52±17		76±29		159±46		103±32	
Chances in 100 that true difference is greater than zero	100		100		100		100		99		100		100	

ferences for the two groups. For ordinary reading, relaxed reading, and reading difficult sounds a difference existed between the groups. In these situations the non-affected group had a lower average number of fixations per line than did the affected group.

Mean duration of fixation. Table II shows the treatment of the mean duration of fixation for the two groups of stutterers. The tendency for values of the non-affected group to remain relatively constant in the oral reading situations is much more marked with regard to average duration of fixation than with regard to average number of fixations per line. In the affected group there is a great deal of variation from situation to situation with respect to mean duration of fixation. Table II indicates that for the silent reading situation the groups are very nearly alike in this eye-movement measure. A small difference between them exists in three situations: reading with *E*, reading while alone, and reading memorized poetry. A comparatively large difference exists in the case of ordinary reading, relaxed reading, and reading difficult sounds.

The variability in mean duration of fixation was great. The SD from the average, given in Table III, represents the deviation of the individual mean duration of fixation from the group mean duration of fixation. The general trend is the same as that in the mean duration itself. The groups are comparable in silent reading, reading alone, and reading with *E*. They show some tendency to be different in the semi-memorized poetry situation, and a definite tendency to be different in the degree of variability in ordinary reading, relaxed reading, and reading difficult sounds.

Another computation was made in order to present more adequately the true variability of average duration of fixation. The SD from the average duration of fixation was computed for each individual for each situation. These individual SDs were then added together. This sum was divided by the number in the group, and the average SD of duration of fixation was the result. This was then treated statistically as a mean and comparisons between the two groups were made by this measure. The results of this treatment are given in Table IV.

The situation is much the same as in the other tables. The values for the non-affected group tend to remain constant in the oral reading situations while those for the affected group vary from situation to situation. The difference between the groups is small in silent reading and reading with *E*. It is somewhat greater for reading alone and for reading semi-memorized poetry, greater still for reading difficult sounds, and relatively great for ordinary reading and relaxed reading.

Average reading time per line. Analysis of the records for average reading time per line are presented in Table V. Here are given the results for both groups, with all the members of the affected group included. Two members of this group gave unusually high scores on this particular measure and a second computation of the measure was made with the values for these two individuals eliminated. Results of this second computation are contained in the lower part of Table V.

The picture here is in general that noted for the other measures. The values in the oral reading situations for the non-affected group again remain relatively constant, while those for the affected group vary quite widely from situation to situation. In both groups the relaxed reading situation is high in mean reading time per line. The two groups respond differently in reading with *E*. The affected group is accelerated in reading time in this situation while the non-affected group is retarded, in comparison with their respective scores for the ordinary reading and relaxed reading situations.

When the two cases giving abnormally high values for this measure were eliminated, the differences between the groups were reduced, but the general distribution of differences, with the exception of transposition of ordinary and relaxed reading situations, remained the same.

Average number of regressions per line. In Table VI are presented the average number of regressive eye-movements per line. In these data we see the picture which is typical in the other measures of eye-movements. In the non-affected group the values for all oral reading situations are relatively constant. The value for relaxed reading and reading with *E* for this group are the highest in the series.

TABLE IV. Standard deviation of mean standard deviation of duration of fixation for affected and non-affected groups of stutters in seven situations (values in ms.)

Group	Oral Reading Situations									
	Silent reading		Ordinary		Relaxed		With E		Alone	
	SD	σ SD	SD	σ SD	SD	σ SD	SD	σ SD	SD	σ SD
Affected	23	.4	129	23	160	29	47	9	22	4
Non-affected	31	.7	27	6	33	7	23	5	35	8
Diff. and PE _{DIFF}	-8 ± 6		102 ± 24		127 ± 30		24 ± 8		-13 ± 9	
Chances in 100 that true difference is greater than zero	90		100		100		100		93	
									100	
									228 \pm 55	
									65	
									14	
									27	
									91	
									17	
									6	
									104 \pm 15	
									100	

TABLE V. Mean reading time per line in sec. for affected and non-affected groups of stutters, in six situations

Group	Oral Reading Situations									
	Silent reading		Ordinary		Relaxed		With E		Alone	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affected	1.76	.55	5.44	3.12	6.95	7.03	3.31	.38	3.56	.83
Non-affected	1.40	.77	2.42	.32	2.92	.32	3.03	.94	2.78	.22
Diff. and PE _{DIFF}	$.36 \pm .30$		3.02 ± 1.23		4.03 ± 1.94		$.28 \pm .35$		$.78 \pm .23$	
Chances in 100 that true difference is greater than zero	88		99		98		79		100	
									96	
									2.95	
									1.22	
									2.24	
									.26	
									.61 \pm .35	
									96	
									2.45	
									1.17	
									2.24	
									.26	
									21 \pm .36	
									96	

Values with two extreme cases in affected group eliminated

Group	Oral Reading Situations									
	Silent reading		Ordinary		Relaxed		With E		Alone	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affected	1.69	.54	4.47	1.93	4.29	1.24	3.27	.44	3.26	.17
Non-affected	1.40	.77	2.42	.32	2.92	.32	3.03	.94	2.78	.22
Diff. and PE _{DIFF}	$.29 \pm .30$		$2.05 \pm .57$		$1.37 \pm .38$		$.24 \pm .36$		$.48 \pm .08$	
Chances in 100 that true difference is greater than zero	83		100		100		74		100	
									21 \pm .36	
									96	

TABLE VI. Mean regressions per line for affected and non-affected groups of stutters in seven situations

Group	Silent reading Mean SD	Oral Reading Situations											
		Ordinary		Relaxed		With <i>E</i>		Alone		Difficult sounds		Poetry	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affected	1.32 1.33	3.35	1.85	4.04	3.17	2.04	1.17	2.65	.96	3.31	1.86	2.29	1.45
Non-affected	1.32 .82	2.24 .78	2.61 .54	2.58 .83	2.40 .88	2.00 .82	1.94 .74						
Diff. and $PE_{diff.}$	.00 \pm .44	1.11 \pm .54	1.43 \pm .83	— .54 \pm .41	.25 \pm .37	1.31 \pm .55	.35 \pm .46						
Chances in 100 that true difference is greater than zero	50	98	96	90	76	99	77						

For the affected group there is the typical picture of variations from situation to situation. Three situations, ordinary reading, relaxed reading and difficult sounds, have high values; reading alone and reading semi-memorized poetry have intermediate values. Reading with *E*, which in the case of the non-affected group was next to the highest, was for this group the lowest of the oral reading situations, and .54 regressions per line lower than the value for the non-affected group.

The most reliable differences are those between the situations in which the affected group has high values. The two groups tend to become alike in silent reading and in those oral reading situations where forces which the stutterer believes operate against his speaking are active. Where the stutterer is on his own responsibility, with *E* as an audience, and when he is given words which he thinks are difficult for him to pronounce, the group which is affected in reading situations tends to exhibit a definite difference from the group which is not affected.

Experimental analysis of eye-voice span in the stutterer. Using the technique of *Lamansky* (13), the following experiment was performed with four stutterers as *Ss*. *S* was asked to fixate a brightly illuminated wedge $\frac{1}{4}$ in. long and $\frac{1}{8}$ in. wide for two minutes in a dark room. As soon as the after-image appeared, enough light was let into the room to enable *S* to read and yet not enough to interfere with the after-image of the wedge. The after-image was in the fovea and its position indicated the point at which the eyes of *S* were fixating.

S was asked to indicate the position of the wedge when he heard a signal. In a first series, the signal was given at a time when *S* was speaking freely. All *Ss* indicated the existence of the eye-voice lead investigated by *Buswell* (3). This lead was relatively narrow, varying from one-half to two ordinary words.

The condition was then studied at the time of the stuttering spasm. A second series of signals was given, each at a time that the stutterer was blocking. With few exceptions the stutterers indicated that the point of the wedge after-image was approximately in the middle of the word being fixated, this being the word in relation to which stuttering was occurring. None of the

Ss reported the point of the wedge over the particular sound associated with the difficulty. In this series there was to be considered *E*'s reaction time from the moment of recognition of the block in the stutterer until the tapped signal was produced.

A third series of signals was given. This time the stutterer was asked to indicate the most advanced point reached by the image of the wedge before the signal was given. Judging from the responses of the four Ss, one of two things happened: either the eyes, as indicated by the wedge, remained on the difficult word until the block occurred, or the image of the wedge proceeded from one-half to two words ahead and then when the spasm occurred, returned immediately to the middle of the word giving the trouble.

Breathing

The breathing records were analyzed quantitatively and qualitatively. Amplitude was measured by considering the vertical distance from the lowest to the highest point of the rising part of the curve in the case of expiration, and from the highest to the lowest point in the falling part of the curve in the case of inspiration. The duration of each inspiration and expiration was measured by considering the distance in mm. the smoked drum moved during the time the breathing movement in question was operative. After means and SDs were computed for duration of inspiration and expiration, the results were divided by 12, since the kymograph speed was 12 mm. per sec. This converted the values from millimeters to seconds.

The method of grouping Ss was the same in this experiment as in the eye-movement experiment. They were classified as non-affected or affected, depending upon whether they did or did not stutter in the experimental situation.

Amplitude of inspiration and expiration. The mean amplitude of inspiration and expiration are presented in Table VII. Inspection shows that for mean amplitude of inspiration the non-affected group is consistently higher than the affected group (no measurement of amplitude of inspiration or expiration was made for the silent reading situation in either group). Both groups vary consistently from situation to situation. Both groups have

comparatively small amplitude for reading with *E* and speaking propositionally. The values for the affected group tend to be much more constant than the values for the non-affected group. The latter condition is opposite to that which prevailed in all measures of eye-movements.

Similar data for the average amplitude of expiration are given in the lower part of Table VII. The values in this table show only minor differences from the values with regard to amplitude of inspiration. The same order holds throughout the table for the averages, the differences between the averages, and the reliability of the differences between the averages.

The two methods of variability computation which were used in average duration of fixation of eye-movements were also used in quantitative measures of the breathing records. First there was the SD of the mean of the individual from the average of the group. This indicates the variability within the group from individual to individual. Second, the mean SD was computed as outlined in the eye-movement data on duration of fixation.

The results of application of the first method appear in Table VIII. Here it is shown that the variability of the non-affected group tends to be consistently greater than that of the affected group in amplitude of inspiration. The difference in variability tends to be small in reading with *E* and speaking propositionally. It rises to an intermediate value for ordinary reading and reading alone, and is greatest for reading difficult sounds. The values from situation to situation in this measure tend to remain constant for the affected group and show much variation for the non-affected group.

Inspection of the lower part of Table VIII shows that what is true for variability of mean amplitude of inspiration holds true for the similar measure of expiration. There is a tendency for the affected group to vary more from situation to situation than in the measure of amplitude of inspiration. The statistical reliability of these measures is not conclusive. There is evidence, however, that some factor in the affected group is operating to cause smaller amplitude and less variability than are present in the non-affected group.

TABLE VIII. Mean standard deviation in mm. of mean amplitude of breathing for non-affected and affected groups of stutterers in free situations

Group	Oral Reading Situations										Speaking propositionally	
	Ordinary		With <i>E</i>				Alone		Poetry			
			Inspiration									
Non-affected	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affected	3.66	.97	3.57	1.64	4.08	2.17	3.73	1.84	3.50	1.27	3.50	1.27
	3.10	.72	3.34	1.85	4.13	1.06	3.43	.94	3.48	1.42	3.48	1.42
Diff. and PE_{DIFF}	.56±.44		.23±.87		— .05±.89		.30±.82		.02±.72		.02±.72	
Chances in 100 that true difference is greater than zero	89		60		52		64		50		50	
Expiration												
Non-affected	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Affected	3.70	1.77	4.07	2.01	3.56	1.21	3.30	1.29	3.72	1.42	3.72	1.42
	3.45	1.23	3.39	1.11	4.43	1.44	3.32	1.04	4.27	1.47	4.27	1.47
Diff. and PE_{DIFF}	.25±.78		.68±.84		— .86±.66		— .02±.64		— .55±.77		— .55±.77	
Chances in 100 that true difference is greater than zero	62		77		90		50		76		76	

TABLE IX. *Standard deviation in mm. of mean standard deviation of amplitude of breathing in non-affected and affected groups in five situations*

Group	Oral Reading Situations					Speaking propositionally
	Ordinary	With E		Alone	Difficult sounds	
		Inspiration				
	SD	SD	σ SD	SD	σ SD	SD
Non-affected	5.84	3.89	1.04	5.90	1.58	3.94
Affected	3.00	2.35	.56	2.63	.62	2.88
Diff. and PE _{Diff.}	2.84 \pm 1.72	1.54 \pm 1.18		3.27 \pm 1.70		1.06 \pm 1.27
Chances in 100 that true difference is greater than zero	94	90		97	98	79
		Expiration				
	SD	SD	σ SD	SD	σ SD	SD
Non-affected	5.97	4.04	1.09	6.06	1.62	3.95
Affected	3.79	2.07	.49	2.76	.65	2.91
Diff. and PE _{Diff.}	2.18 \pm 1.84	2.02 \pm 1.20		3.30 \pm 1.74		1.04 \pm 1.29
Chances in 100 that true difference is greater than zero	87	94		96	97	79

The average SD and the sigma of this average for the amplitude of inspiration and expiration appear in Table IX. From inspection of this table it is apparent that the difference in variability between the two groups noted in the previous computation largely disappears. For neither inspiration nor expiration does the difference between the variability of the two groups ever reach one mm. in the excursions of the styli on the kymograph. The statistical reliability of the difference in both measures is low, the highest probability that the observed difference is a true difference being 89 out of 100 in the case of ordinary reading, for amplitude of inspiration, and 90 out of 100 in reading alone, for amplitude of expiration.

Duration of inspiration. In Table X appear the measures of breathing for mean duration of inspiration. It is obvious that for all situations except reading with *E* and silent reading, the affected group has longer mean duration of inspiration than the non-affected group. However, there is an abrupt rise in the value for the non-affected group in speaking propositionally.

In agreement with the measures of eye-movements and in contrast to the measure of amplitude of breathing, the values for the duration of inspiration for the non-affected group in the oral reading situations tend to remain constant with the exception of speaking propositionally. The values for the affected group vary widely. When the averages and the reliability are taken into consideration there is an indication that for silent reading and reading with *E* the two groups are similar. They tend to approach each other in speaking propositionally, where the value for the non-affected group makes the sharp rise upward in duration of inspiration noted above. In other situations the differences between the groups are quite marked.

In Table XI is presented the SD of mean duration of inspiration, which indicates the variation of the performance of each individual from the average of the group. Inspection of this table shows that, with the exception of the silent reading situation, the variability of the affected group is greater than that of the non-affected group. In oral reading the values for the non-affected group tend to be constant while those of the affected

TABLE X. *Mean duration of breathing in ms. of non-affected and affected groups in six situations*

Group	Silent reading	Oral Reading Situations						Speaking propositionally	
		Ordinary	With <i>E</i>		Alone		Difficult sounds		
			Inspiration						
	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD		
Non-affected	1416 351	554 107	616 80	580 84	546 112	737 117			
Affected	1440 309	842 427	544 152	725 225	641 198	857 247			
Diff. and PE_{DIFF}	-24 ± 188	-288 ± 147	-72 ± 69	-145 ± 82	-95 ± 84	-120 ± 103			
Chances in 100 that true difference is greater than zero	56	97	87	96	86	87			
Expiration									
	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD	Mean SD		
Non-affected	1912 378	3604 971	4074 917	3625 917	4435 1597	3642 771			
Affected	1743 252	4302 1153	3996 488	4070 624	4340 704	4300 1039			
Diff. and PE_{DIFF}	169 ± 178	-698 ± 531	78 ± 382	-445 ± 441	95 ± 652	-658 ± 488			
Chances in 100 that true difference is greater than zero	82	90	58	84	56	90			

TABLE XI. *Standard deviation in ms. of mean duration of amplitude of breathing in non-affected and affected groups of stutterers in six situations*

Group	Silent reading	Oral Reading Situations					Speaking propositionally
		Ordinary	With E		Alone	Difficult sounds	
			Inspiration				
	SD σ SD	SD σ SD	SD σ SD	SD σ SD	SD σ SD	SD σ SD	SD σ SD
Non-affected	351 101	107 29	122 33	84 22	112 32	117 31	
Affected	309 77	427 100	152 36	225 53	198 50	247 66	
Diff. and PE _{DIFF}	42 \pm 127	-320 \pm 104	-30 \pm 49	-141 \pm 58	-86 \pm 56	-130 \pm 73	
Chances in 100 that true difference is greater than zero	62	100	73	99	93	96	
			Expiration				
	SD σ SD	SD σ SD	SD σ SD	SD σ SD	SD σ SD	SD σ SD	
Non-affected	378 109	971 259	955 255	917 245	1597 461	771 206	
Affected	252 63	1153 271	448 115	824 194	704 176	1039 291	
Diff. and PE _{DIFF}	126 \pm 126	-182 \pm 376	507 \pm 280	93 \pm 313	893 \pm 493	-268 \pm 357	
Chances in 100 that true difference is greater than zero	84	67	96	60	96	77	

group tend to vary from situation to situation. Reliability of the differences is high in all situations except reading with *E* and silent reading, where the differences between the two groups are small.

When the second measure of variability, that of mean SD of duration of inspiration, was applied, the results were as indicated in Table XII. Here the tendencies indicated in the mean and SD discussed above are even more definite with the exception of speaking propositionally. By this measure the latter situation is grouped among the situations in which the values for the two groups tend to enter the same statistical population.

Duration of expirations. Average durations of expiration and their SDs, for the affected and non-affected groups, appear in the lower part of Table X. It can be seen that in this measure, as in the measures of amplitude of breathing, the values for the affected group in the oral reading situations tend to be constant while those of the non-affected group vary from situation to situation. The widest range between any two situations for the affected group is that of 344 ms. between reading with *E* and reading difficult sounds. The widest range between any two oral reading situations for the non-affected group is that of 791 ms. between ordinary reading and reading difficult sounds. The values for the affected group, in addition to being more constant, are in general higher, indicating a longer duration. However, in reading with *E* and reading difficult sounds the duration of expiration is a little higher for the non-affected group. In reading with *E*, values for the affected group drop to the lowest point for the oral reading situations, while those for the non-affected group rise to next to the highest. Apparently the non-affected group is disturbed by *E*'s reading along with them while the affected group is influenced in such a way as to reduce favorably the mean duration of expiration as compared with the other situations.

The variability of the mean duration of expiration for the individual from the mean of the group is given in the lower part of Table XI. Inspection shows that both groups vary widely from situation to situation. However, the affected group vary

TABLE VII. *Mean standard deviation in ms. of mean duration of breathing in non-affected and affected groups of stutterers in six situations*

Group	Silent reading	Oral Reading Situations						Speaking propositionally
		Ordinary	With \bar{E}		Alone	Difficult sounds		
		Mean	SD	Inspiration	Mean	SD	Mean	SD
Non-affected	208 155	154 58	216 88	213 47	180 97	302 132		
Affected	318 238	504 606	212 16	405 224	326 255	247 324		
Diff. and PE _{DIFF.}	-20±105	-450±203	-4±48	-192±77	-146±98	-24±132		
Chances in 100 that true difference is greater than zero	56	99	52	99	93	56		
		Mean	SD	Expiration	Mean	SD	Mean	SD
Non-affected	266 136	1169 228	1462 466	1140 228	1503 586	1671 527		
Affected	267 146	2081 761	1442 284	1625 479	1735 1136	2124 1323		
Diff. and PE _{DIFF.}	-1±98	-994±268	20±212	-485±182	-232±467	-453±536		
Chances in 100 that true difference is greater than zero	56	100	52	99	67	79		

less in all situations except ordinary reading and propositional speaking.

When the mean SD was considered the results were those presented in the lower part of Table XII. In the mean SD a condition appears which contrasts with the conditions indicated by the SD of the group. Inspection of the table shows that the affected group has the greatest variability in all situations except reading with *E*. The two groups were the same for the silent reading situation.

When the mean SDs of duration or expiration are compared with the means themselves, it appears that, for silent reading, reading with *E*, and reading difficult sounds, the affected and non-affected groups tend to be members of the same statistical population. They tend to be members of two populations in ordinary reading and in reading while alone. In propositional speaking the picture is somewhat confused. The unreliability of the difference in this situation tends to indicate that the two groups are alike.

In summarizing the quantitative study of breathing it may be said that the mean amplitude of inspiration and expiration is greater for the non-affected than for the affected group; the variability of these measures is greatest in the non-affected group when the SD of the group and mean SD are considered. Mean duration of inspiration is greater in the affected group in all speaking situations except reading with *E*. The value for the non-affected group rose abruptly for the propositional speaking situation. The greatest variability for mean duration of inspiration was in the affected group. For mean duration of expiration, values tended to be constant but high in the affected group; they tended to vary widely in the non-affected group. The two methods of computing variability tend to contradict each other in this measure. The mean SD tends to agree with the means.

Considering all measures, there seem to be certain situations where the two groups are alike, *e.g.*, in silent reading, reading with *E*, reading difficult sounds and speaking propositionally (as indicated by most measures). They seem to be different in read-

ing alone and ordinary reading. Reliability of these measures of breathing is low.

Analysis of expressed abnormalities. An analysis was made of the breathing records used in the quantitative study for the frequency of appearance of certain types of abnormalities, the frequency of appearance in the various situations, and their relation to the signalled overt spasm.

Before considering these abnormalities, attention is called to the two general phenomena which were observed. In some stutters those phenomena were characteristic for all situations, in others they appeared occasionally. The first was that either the thorax or the abdomen leads in time in a given breathing cycle. This condition usually occurred at the beginning of either the inspiratory or the expiratory phase. A record in which the abdomen leads in expiration is presented in Fig. 1, No. 1. There is an independent expiratory movement in the abdomen which is not reflected in the curve of the thorax. Usually it was the abdomen that was the offender, but in one individual the thorax exhibited such abnormal activity (Fig. 1, No. 2).

In certain cases where the above condition existed it seemed to have some relation to frequency of the signalled overt spasm. WAL is a case in point. Fig. 1, Nos. 3 and 4, show sections taken from records of this S in two situations. The section at the left shows the condition present in the difficult sounds situation (note the signalled spasms in the top line). On the right is shown a section from the record for reading with E. There are no signalled spasms and the lead of the abdomen has largely disappeared. On the other hand ANDE gave records which showed this abdominal lead to be present in only one situation, that of reading while alone.

Another phenomenon that seemed to be characteristic of certain stutters was the appearance in either the thorax or the abdomen of tremors of either abnormally great amplitude or high frequency. Fig. 1, No. 5, illustrates a case of great amplitude (abdominal) and Fig. 1, No. 6, shows a thoracic tremor. Travis (18) reports mild tremors as characteristic of normal speakers. In certain Ss in the present study the intensity of the

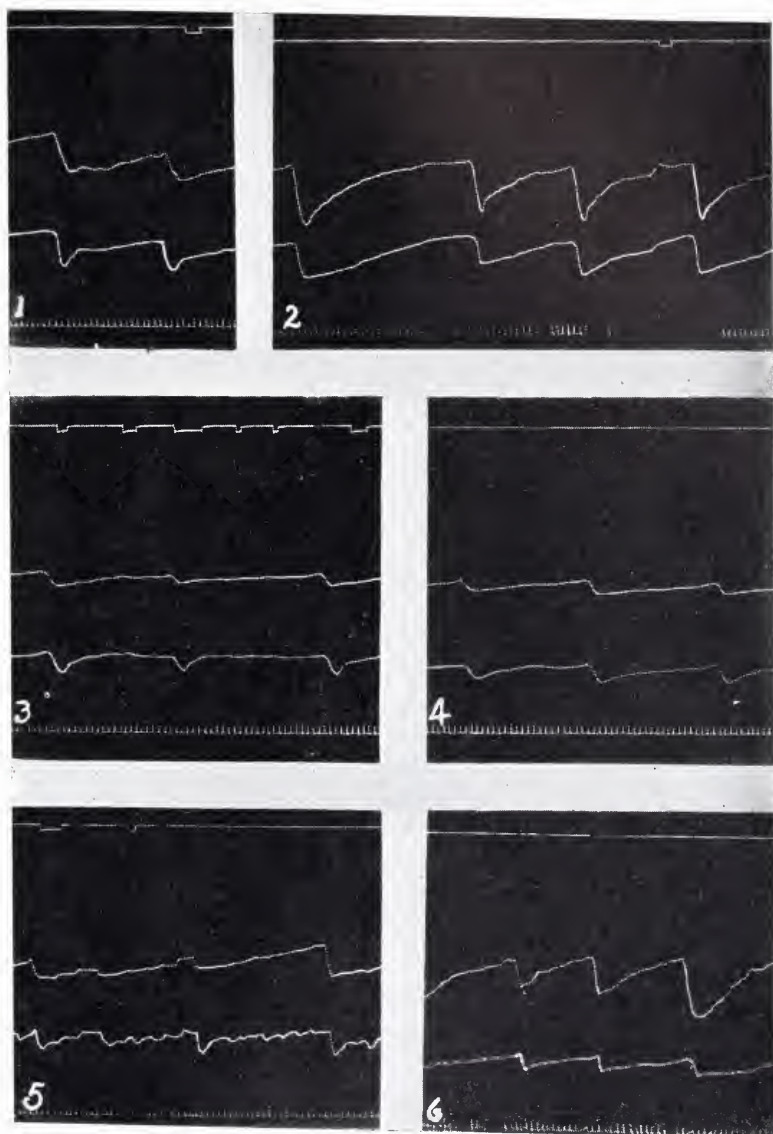


FIG. 1. Types of breathing abnormalities

- No. 1. Abdomen leads in expiration.
- No. 2. Thorax leads in expiration.
- No. 3. Abdominal lead in relation to many spasms in the reading difficult sounds situation.
- No. 4. Record from same *S* as No. 2 during reading with *E*. Abdominal lead has disappeared and no spasms occurred.
- No. 5. Tremor of great amplitude in the abdomen.
- No. 6. Tremor in the thorax.

tremor seemed to vary from situation to situation but not to have any relation to the signalled spasm as such. A high frequency tremor is illustrated in Fig. 2, No. 1. Its frequency is about 12 per sec.; it appears in both the thorax and abdomen between two signalled spasms.

A count was made of three general types of abnormalities: oppositions, interruptions, and abnormal durations. When the curves from the thorax and abdomen were converging or diverging at the same moment of time, the phenomenon was termed opposition. This is illustrated in Fig. 2, No. 2. Interruptions were of three kinds: (1) tonic interruption—in this type the upward progress of the curve was interfered with and a plateau would appear on the curve (Fig. 2, Nos. 3 and 4—note the relation of the signalled spasms); (2) clonic interruption—curves in which there appeared rapid alternation of inspiration and expiration superimposed upon the regular curve pattern (Fig. 2, No. 5); (3) reversals—a single interruption of an expiration by a short inspiratory phase or vice versa (this occurred quite frequently and so it was given a separate classification). Abnormal duration was difficult to determine. It was done purely by inspection. There is such a wide variation of the breathing duration curves in normal speakers that of these records only the very short or very long were considered abnormal.

The frequency of the above abnormalities is recorded in Table XIII for the non-affected group and in Table XIIIa for the affected group. These show that for the non-affected group there were 314 curves with abnormalities in a total of 989 breathing curves. For the affected group 660 out of a total number of 1,126 curves exhibited abnormalities.

Two of nine *Ss* in the affected group gave records in ordinary reading, reading difficult sounds, and speaking propositionally that were too complicated to analyze. One of these gave tonic interruptions on every curve for one situation and many of the same type in other situations. Since this was characteristic of only one individual, these tonic interruptions were not included in the computation. The bottom line of the table gives the percentage of the total number of curves in all situations exhibiting

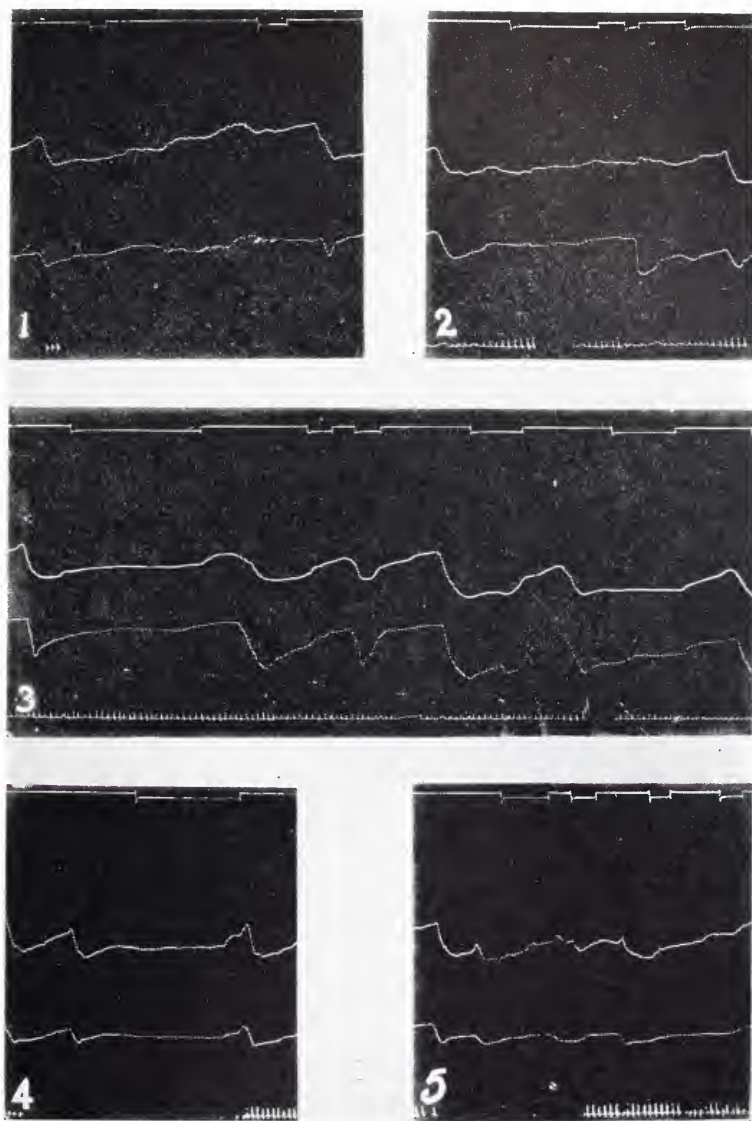


FIG. 2. Types of breathing abnormalities

No. 1. Tremor of high frequency appearing in both thorax and abdomen between two signalled spasms.

No. 2. Opposition between thorax and abdomen occurring in relation to signalled spasms.

No. 3. A series of tonic interruptions bearing direct relation to signalled spasms.

No. 4. A single tonic interruption in relation to spasm.

No. 5. Clonic interruption in relation to spasms.

TABLE XIII. Number of curves exhibiting one or more types of breathing abnormalities in seven speaking situations for the non-affected group

Situation	No. of curves	Interruptions				Abnormal durations			
		Oppositions		Tonic		Reversals		Long	
		In.	Ex.	In.	Ex.	In.	Ex.	In.	Ex.
Ordinary reading	150	—	2	—	1	1	2	—	3
Relaxed reading	137	—	—	2	9	—	1	—	3
Reading with experimenter	143	—	11	—	—	5	7	—	10
Reading while alone	148	—	—	—	34	7	2	—	1
Reading difficult sounds	113	—	5	—	15	—	3	—	1
Reading familiar poetry	150	—	4	—	19	1	4	—	2
Speaking propositionally	128	—	4	—	48	1	2	—	2
Totals	969	0	28	2	170	5	26	0	22
Percentage		0	2.9	.2	17.5	.5	2.6	0	2.2

TABLE XIIIa. Number of curves exhibiting one or more types of breathing abnormalities in seven speaking situations for the affected group

Situation	No. of curves	Interruptions				Abnormal durations			
		Oppositions		Tonic		Reversals		Long	
		In.	Ex.	In.	Ex.	In.	Ex.	In.	Ex.
Ordinary reading	165	—	5	—	82	2	4	2	7
Relaxed reading	189	—	3	—	61	1	4	—	6
Reading with experimenter	188	—	—	—	29	6	8	—	4
Reading while alone	145	—	5	—	28	2	1	—	4
Reading difficult sounds	146	—	—	—	79	4	4	—	2
Reading familiar poetry	163	—	3	—	88	5	4	1	2
Speaking propositionally	130	—	4	—	76	2	1	2	6
Totals	1126	0	20	0	443	12	15	5	28
Percentage		0	1.7	0	39.3	1	1.3	.4	2.4

that type of abnormality listed at the top of the column. For all types, with the exception of oppositions, there was consistently a much lower frequency among the non-affected than among the affected group.

In the last column of Tables XIII and XIIIa are given the percentages of the total number of curves that exhibit abnormalities in each of the situations. For the non-affected group the highest percentages of abnormal curves were in ordinary reading, reading with *E*, and speaking propositionally. The lowest percentages were in relaxed reading, reading difficult sounds and reading familiar poetry. For the affected group five situations show a high percentage of curves containing abnormalities. These are ordinary reading, relaxed reading, reading difficult sounds, reading familiar poetry, and speaking propositionally. Two situations had a low score, namely, reading with *E* and reading while alone. In the affected group the situation in which the *Ss* read familiar poetry produced the greatest number of abnormal curves. This situation proved very difficult for some members of this group.

These data indicate that in both groups the frequency of abnormalities varies widely from situation to situation. The non-affected group seem more disturbed by reading with *E*, since the number of abnormal curves is greatest in this group for this situation. The affected group, on the contrary, has the lowest count of abnormal curves for this situation. The instruction to read in a relaxed manner seemed to have an effect on the breathing of the non-affected group, since the smallest number of abnormal curves for this group was in this situation. Difficult sounds and reading familiar poetry gave a low count for this group, while frequency of abnormalities in speaking propositionally rose abruptly. In this situation there also appeared quite a number of overt spasms in the non-affected group.

The records were analyzed for the relationship between the appearance of the abnormality and the signalled overt spasm. This information was available in five of the situations. In silent reading, reading while alone and reading with *E*, no adequate signalling of the spasms if they occurred was possible.

Table XIV gives the data for this analysis. Only three types of abnormality, tonic interruption, reversal on inspiration, and long duration, show relation to the signalled spasm in the non-affected group. Only 17.7 per cent of the curves exhibiting abnormalities had any relation to the signalled overt spasms.

TABLE XIV. *Number of observed abnormalities that bear relation to signalled overt spasm in five situations*

		Total No.	No. related to spasm	Per cent related to spasm
Non-Affected Group				
Ordinary reading	Tonic interruption—exp.	21	5	23
Reading familiar poetry	Tonic interruption—exp.	19	1	5
Speaking propositionally	Tonic interruption—exp.	48	8	16.6
	Reversals—exp.	10	2	10
	Abnormally long duration—exp.	9	3	33.3
Total curves exhibiting indicated abnormalities in above situations		107	19	17.7
Total curves exhibiting tonic interruption		170	14	8
Affected Group				
Ordinary reading	Oppositions—exp.	5	3	60
	Tonic interruption—exp.	82	75	91
	Clonic interruption—exp.	4	2	50
	Reversals—exp.	7	1	14
Relaxed reading	Opposition—exp.	3	2	66
	Tonic interruption—exp.	61	49	80
	Clonic interruption—exp.	4	2	50
	Reversals—insp.	13	5	38
	Reversals—exp.	15	1	6.5
Reading difficult sounds	Tonic interruption—exp.	79	56	70
	Reversals—insp.	4	2	50
	Reversals—exp.	4	1	25
Reading familiar poetry	Tonic interruption—exp.	88	79	90
	Reversals—insp.	10	3	33.3
	Abnormally long duration—insp.	1	1	100
	Abnormally long duration—exp.	2	1	50
Speaking propositionally	Tonic interruption—exp.	76	59	77
	Reversals—insp.	4	1	25
	Reversals—exp.	9	2	22
	Abnormally long duration—insp.	2	2	100
Total curves exhibiting indicated abnormalities in above situations		473	347	73.3
Total curves exhibiting tonic interruption		386	318	84.5

The data for the affected group show that 345, or 73.3 per cent of the 473 curves showing abnormalities, had some relation to a signalled overt spasm.

From these data it would appear that the tonic interruption type of abnormality is the one outstanding type of breathing abnormality with a high relation to the signalled overt spasm. However, this type of abnormality appears quite frequently in the non-affected group, while only eight per cent of them are related to signalled spasms.

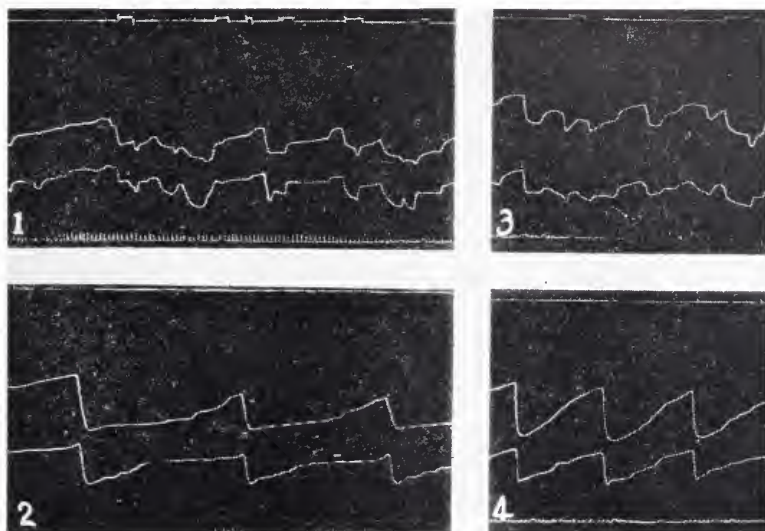


FIG. 3. Change of general form accompanying changes in the speaking situation

No. 1. Section of record from SEL during ordinary oral reading. Note tonic interruption on inspiration and expiration in relation to spasms.

No. 2. Record of same *S* during reading with *E*.

No. 3. Record of SEL in reading a section of *Drink to Me Only with Thine Eyes*.

No. 4. Record from same *S* when the same words were sung.

The signalling of overt spasms is difficult, and in all probability some spasms bearing relation to this tonic interruption type of abnormality were missed by *E*. It is significant, however, that for the affected group this type has such a high frequency in relation to the signalled spasms—84.5 per cent of the total number of curves exhibiting this type of abnormality were so related.

In the affected group there also was a fairly close relation

between reversals on inspiration and the signalled spasm, some relation between the spasm and the opposition type of abnormality, and some between the spasm and reversal on expiration.

In some cases there was a tendency for the general pattern of the curve to change with the situation. Fig. 3, Nos. 1 and 2, show records of SEL. No. 1 is a section of the breathing record during the ordinary reading situation. The pattern is so complicated as to defy analysis. There are long inspirations, interrupted by periods of expiration and many tonic interruptions. Expiration is similarly interrupted. There are also many and long signalled spasms. No. 2 is a section taken from this S's record during reading with E. Apparently the fact that E was sharing the responsibility and setting the pace was effective to the point where the gross general abnormalities exhibited in the record from ordinary reading largely disappeared. The pattern is definite and fairly, though not completely, normal. There is a tendency to begin and end each expiration with a short period of more rapid exhalation than is the case in the central portion of the record.

Fig. 3, Nos. 3 and 4, present a similar contrast from the same individual. No. 3 is a passage from *Ben Jonson's* "Drink to Me Only With Thine Eyes." There is a great deal of dysintegration in the record. In No. 4 is recorded the same selection when the stutterer was asked to sing it. The curves here are vigorous and definite and are apparently normal.

To summarize this part of the study, which deals with analysis of abnormalities of breathing records, it can be said that the frequency of appearance of abnormalities varies from situation to situation. The most frequent type of abnormality was the tonic interruption of expiration. The next most frequent was the reversal on inspiration and expiration. Other types were very infrequent.

In addition to appearing more frequently, the tonic interruption type has the highest frequency of relation to the signalled overt spasm. In the affected group 84.5 per cent of curves of this type were related to a signalled overt spasm. The other types of

abnormality show a low degree of relation with the signalled spasm. Some types show no apparent relation whatever.

Action Currents from the Masseter Muscles

The records of action currents from the masseter muscles were analyzed for the following: (1) changes in frequency of appearance of recognized abnormalities associated with changes in the speaking situation; (2) mean percentage of total time in each

TABLE XV. *Frequency of appearance of all types of action current abnormalities in records of ten stutterers taken during one silent reading, five oral readings, and one propositional speaking situation*

	Silent reading	Oral Reading Situations				Speaking propositionally
		Ordinary	Reading with E	Alone	Difficult sounds	
YAN	0	1	4	11	20	7
EDM	0	21	15	20	34	18
ROS	0	11	8	9	28	22
GOO	0	17	0	6	4	22
ROG	0	12	6	7	21	8
LOD	0	16	10	15	54	48
IRV	0	16	15	13	30	9
BAR	0	19	20	8	45	33
SEL	0	28	2	0	48	37
WAL	0	11	18	32	33	30
Total	0	152	98	121	317	234
Frequency based on uniform number of 500 words	0	118	87.4	93	120.8	(101)*

* Estimate.

situation during which abnormalities were present in action currents; (3) relation of action current abnormality to signalled overt spasm; and (4) frequency of appearance of the various types of action current abnormalities.

Changes in the frequency of appearance of action current abnormalities that accompany changes in the speaking situation. Table XV gives the frequency of abnormalities for 10 stutterers in six speaking situations. The length of the speaking situations were not the same. The total number of words in the silent reading and the oral reading situations varied as follows: silent

reading, 590; oral reading, 640; reading with *E*, 560; reading alone, 650; reading difficult sounds, 1,312. The number of words spoken propositionally is not known.

To make the situations more comparable, computation was based upon the supposition that, considering all *Ss*, the tendency for abnormalities to appear was uniformly distributed throughout the situation. The number of words in each situation was reduced to 500 and the number of action current abnormalities was reduced proportionally. The bottom line of Table XV gives the frequency of abnormalities, computed in this way. The figure for speaking propositionally is an estimate arrived at by considering propositional speech as consuming .7 sec. per word.

From this lower line of the table it is seen that for ordinary reading and difficult sounds the number of action current abnormalities is approximately the same. Likewise reading with *E* and reading alone gave approximately the same number of abnormalities. There were 75.3 per cent as many abnormalities in the latter two situations as in the former two. In silent reading there was at no time any abnormality whatsoever, indicating that the abnormalities are connected with the act of speaking and are not manifested until that act is in progress.

These data indicate that broad changes in the type of speaking situation are accompanied by changes in the frequency of appearance of action current abnormalities. The grouping of the situations in this experiment agrees with the groupings found most frequently in the eye-movement and breathing experiments.

Percentage of total time during which the abnormalities in action currents were operative. The duration of abnormalities varied widely. The duration of each was recorded and the percentage of time during which the abnormalities were operative was computed for each individual for each situation. The average percentages of time are presented in Table XVI. The table shows that the percentage of time varies from situation to situation. The ordinary reading situation is the highest; speaking propositionally and reading difficult sounds are lower and about the same; reading with *E* and reading alone show the lowest percentages. In reading with *E* one *S* gave an unusually

high percentage of total time, 72.1. This was more than 28 per cent higher than for any other situation for him and was the highest percentage of the entire group in any situation. If this score is eliminated from the computation, reading with *E* showed, for the entire group, 16 per cent of the total time taken up by abnormalities. Only four individuals had scores above 10 per cent of the total time for this situation. The value of this measure of duration is probably low due to the fact that there is such a marked variation in the relation of the abnormality to the overt spasms, as will be shown later. It indicates that the time

TABLE XVI. *Percentage of total recorded time during which action current abnormalities were operative in the masseter muscles of 10 stutterers in six situations*

	Silent reading	Oral Reading Situations				Speaking propositionally
		Ordinary	Reading With <i>E</i>	Alone	Difficult sounds	
YAN	0.0	0.2	3.0	17.6	7.7	2.5
EDM	0.0	50.0	11.6	28.1	45.0	35.3
ROS	0.0	66.7	40.6	31.3	26.2	31.2
GOO	0.0	30.7	00.0	20.3	3.6	24.5
ROG	0.0	54.3	10.8	24.1	16.7	16.1
LOD	0.0	29.2	27.6	18.2	38.4	34.5
IRV	0.0	63.3	37.4	37.1	24.8	40.3
BAR	0.0	46.4	72.1	14.1	37.8	26.2
SEL	0.0	18.0	2.0	00.0	25.0	33.0
WAL	0.0	8.3	11.5	13.0	21.0	6.7
Mean		36.7	21.7	20.4	24.6	25.0

abnormalities are in progress is really of considerable extent, and that it does vary from situation to situation, as does the frequency of appearance of the abnormalities themselves.

Relationship between the action current abnormalities and the signalled overt spasm. Out of the six situations in the action current study there were only three that could be used in this part of the investigation: ordinary reading, reading difficult sounds, and speaking propositionally. For stutterers who have tonic blocks of long duration the overt spasm can be quite accurately signalled (Fig. 4, No. 1) but for *Ss* who exhibit the rapid clonic type of spasm it is most difficult to get all of the spasms. Of the 10 stutterers used in this experiment four were of the latter type.

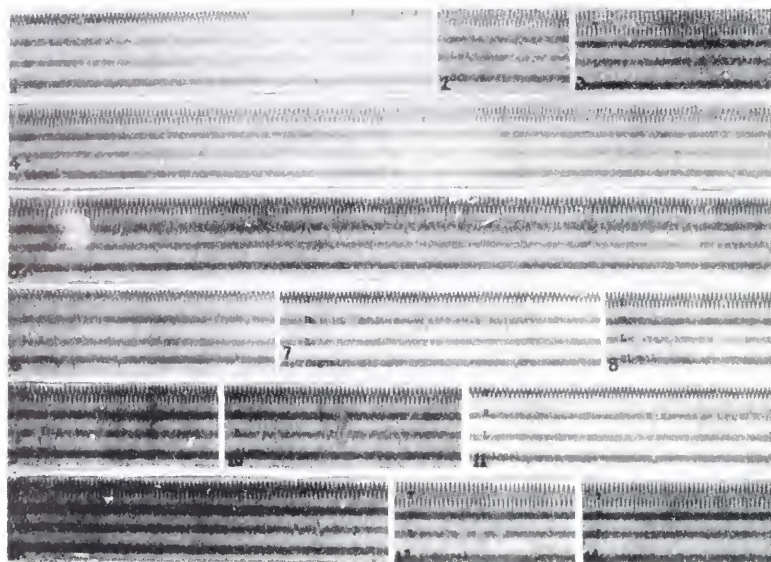


FIG. 4. Abnormalities in action current records from the masseter muscles

No. 1. Abnormality approximately even on both sides and bearing definite relation to the signalled overt spasm.

No. 2. Single spikes, first on one side and then on the other.

No. 3. Single spikes on one side, followed by primary abnormality on same side in relation to signalled spasm.

No. 4. Long signalled spasm without appearance of abnormality.

No. 5. Greater intensity on one side than on the other during a long signalled spasm.

No. 6. Abnormality alternating from side to side in relation to two spasms.

No. 7. Abnormality on right side only—two such periods of abnormality in relation to two spasms.

No. 8. Abnormality entirely on left side.

No. 9. Abnormality beginning on the left then shifting to even on both sides.

No. 10. Abnormality beginning on left shifting to even on both sides then shifting back to the left to end of spasm.

No. 11. Secondary abnormality in relation to short spasm, followed by primary abnormality which begins on left and then shifts to the right to the end of the spasm (last signal not shown).

Nos. 12, 13, 14. Records in which the signal and spasm precedes the abnormality.

Six types of relationship between the signalled spasm and the appearance of the action current abnormality were determined: (1) a type of abnormality which has been designated as single spikes, where the abnormality is not continuous but is present in

the form of one, two, three, or more single spikes with apparently normal action currents in between—examples of this type of abnormality are given in Fig. 4, Nos. 2 and 3; in these three situations few of this type occurred without being related to the signalled spasm; (2) a signalled spasm without any accompanying abnormality whatsoever (Fig. 4, No. 4); (3) a low amplitude abnormality, termed a secondary abnormality—many of these were related to a signalled spasm (see slight abnormality on *R* line in relation to first signal in Fig. 4, No. 11); (4) a primary abnormality, or one in which the amplitude was large (Fig. 4, Nos. 1, 5, 7, 8); (5) a secondary abnormality with no accompanying signal; (6) a primary abnormality with no accompanying signal.

Table XVII shows the frequency of these six types of relations for the three situations in which there was an opportunity to signal the overt spasms. Reduced to the most general and simple terms, there are three possible relations between spasm and signal: (1) signal without abnormality, (2) signal with abnormality, (3) abnormality without signal. In these terms 108, or 15 per cent of the 733 possible relations, were that of signalled spasm with no accompanying abnormality; 147, or 20 per cent, were abnormality with no signal; and 478, or 65 per cent, were signal with an action current abnormality.

The relation between the signalled overt spasm and the action current abnormality seems to be quite close. The fact that the other two possibilities occur so often precludes the possibility of the relationship's being a one-to-one affair unless one of two things occurred at the time the record was taken. First, the signal without abnormality may be merely an index that the individual had paused, although the length of some of them makes this improbable. Second, the spasms may have been present in the case of abnormalities without signal without being recognized by *E*. Undoubtedly some were missed, but hardly as many as the findings would indicate.

The signal preceded the abnormality 114 times in the three situations investigated. The records given in Fig. 4, Nos. 12, 13, 14, show examples of this condition. However, one indi-

TABLE XVII. Frequency of appearance of six types of action, current abnormalities and signalled overt spasm relation from records of 10 stutterers in three situations where all types of relation had an equal chance of occurring

Subjects	Single spikes	Signal without abnormality	Signal with secondary abnormality	Signal with primary abnormality	Secondary abnormality without signal	Primary abnormality without signal
YAN	4	16	2	13	2	7
EDM	0	5	21	47	5	0
ROS	0	4	0	18	0	4
GOO	0	4	0	39	0	4
ROG	2	7	93	13	3	20
LOD	4	17	32	29	0	3
IRV	4	5	4	19	3	25
BAR	3	10	25	55	1	15
SEL	6	23	12	83	3	0
WAL	0	17	10	21	2	32
	32	108	109	337	28	119
Summary						
Signal and no abnormality				108 = 15%		
Signal with abnormality				478 = 65		
Signal without abnormality				147 = 20		
Total				733 = 100%		

vidual accounted for 56 of these instances. For this particular *S* this was a characteristic of the signal-abnormality relation.

Frequency of appearance of various types of action current abnormalities. Travis (18) has called attention to the striking differences between the action currents recorded from the two masseter muscles during stuttering. In the analysis of records secured in this experiment it was found that seven of the 10 *Ss* gave action currents during normal speech that were very small in amplitude compared with the results of most normal speakers. Frequently, at the time of the stuttering spasm, there was an abrupt increase in amplitude (usually expressed in volleys). While in the majority of the cases one of the two sides exhibited this increase to a greater extent than did the other side, there were many instances in which the two sides were equally active in showing this increased amplitude (Fig. 4, No. 1). Its relation with the signalled spasm was such that in the following report on the frequency of different types of abnormalities it has been included.

The analysis consisted of determining the frequency of the following types of abnormality: (1) even from side to side but increased in amplitude (Fig. 4, No. 1); (2) greater amplitude on one side than on the other (Fig. 4, Nos. 3, 5); (3) alternating from side to side (Fig. 4, No. 6); (4) all on one side (Fig. 4, Nos. 7, 8); (5) beginning on one side, then shifting to equality of the sides, or beginning equally and then shifting to one side and then perhaps back to even again (Fig. 4, Nos. 9, 10, 11).

The distribution of these five types of abnormalities in the situations for the 10 *Ss* is given in Table XVIII. In the last column is given the side upon which the abnormality appeared most frequently during the entire series of situations. From this column we see that EDM and BAR were alike in that they show about an even distribution of the abnormalities between the right and left sides. WAL gave an even distribution between abnormalities that were even on both sides and those that appeared predominantly on the right side. Four gave records in which the abnormalities were predominantly on the left side, and three gave records in which the abnormalities were predominantly on the right.

TABLE NVIII Frequency of appearance of five types of action current abnormalities from records of 10 stutters in six situations

	Even	Greater amplitude one side	Alternating	All on one side	Beginning one side and shifting	Most active side
Control						
MAN	4	6	2	28	3	Left
EDM	14	11	0	63	20	Right or left
LOS	9	37	1	21	10	Right
GOO	4	14	0	28	3	Right
ROG	15	15	2	19	3	Right
LOD	18	33	1	75	16	Left
URA	7	14	3	45	14	Left
BAR	46	27	11	19	22	Left or right
SEL	1	2	13	74	24	Left
WAL	93	6	0	26	2	Even and right
Total	211	165	33	398	117	924
Percentage of all types	22	18	4	43	13	100
Summary						
Even on both sides						
Predominantly on one side						
Shifting between both sides						
Total						
				211 = 22%		
				563 = 61		
				150 = 17		
				924 = 100%		

That type of abnormality which was all on one side gave the highest frequency of all, 43 per cent of the total being of this kind. The five types may be reduced to three general types as follows: (1) even on both sides; (2) abnormality predominantly on one side; (3) abnormality shifting between the two sides, either alternating or starting or ending with greater amplitude on one side. In these terms 22 per cent were of the even type, 61 per cent were predominantly on one side, and 17 per cent were characterized by shifting from one side to the other.

In the section on the relation between the signalled overt spasm and the abnormalities of the action current record, it was pointed out that all of these types of action current abnormalities occur in relation to the signalled overt spasm. Apparently there is little evidence from these data that any certain form of action current has any definite relation to the stuttering spasm as such. To illustrate the ambivalent nature of the forms of abnormalities appearing in the same individual in one situation, a series of records are given in Fig. 5, Nos. 1, 2, 3, 4, 5. They are given in order of appearance in the reading difficult sounds situation. No. 1, at the top, shows first an abnormality of secondary degree, which is related to a short signalled spasm, followed by an abnormality of primary degree which appears on the right and is accompanied by a longer spasm. Note that throughout these records the signal follows the abnormality consistently by the same amount of time. Apparently this was the time it took for the abnormality to become evident, plus *E*'s reaction time.

The next record shows the abnormality beginning on the left and then shifting to even toward the end of the spasm. The abnormality in No. 3 begins on the left and stays predominantly on the left, although there is some shifting to the right. Note the differences between the frequencies of the volleys from the two sides. In record No. 4 an abnormality of primary degree is predominantly on the left and is accompanied by a signalled spasm, the end of the spasm not being shown. In No. 5 the abnormality starts on the left, then shifts quickly to the right, disappears, reappears again on the right, and finally at the break

of the spasm on the left side cuts in. All of these types occurred in the same situation.

From these data, since so many types can occur in the same

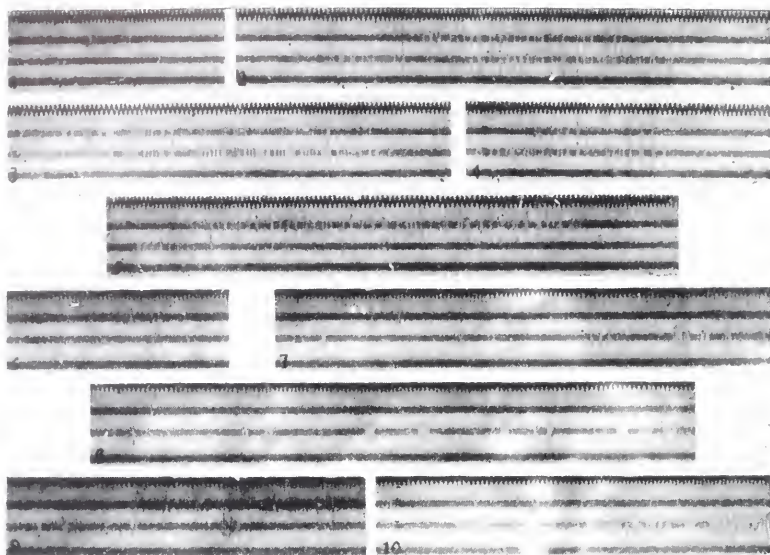


FIG. 5. Abnormalities from action currents of masseter muscles. (Nos. 1, 2, 3, 4, 5, are all from the same stutterer in the oral reading of difficult sounds situation. Nos. 6, 7, 8, 9, 10, are records made by the writer in simulating action current abnormalities of stutterers.)

No. 1. Slight abnormality on right followed by short spasm. Then abnormality on right followed by longer spasm.

No. 2. Abnormality begins on left then shifts to even on both sides to end of spasm.

No. 3. Abnormality almost even on both sides at the beginning, it drops out on the right at end of spasm.

No. 4. Abnormalities begin on left, right sides come in with volleys approximately half as frequent as those from the left.

No. 5. Abnormality on the left, the right side cuts in, then the left side cuts out to the end of the spasm except for a secondary volley occasionally.

No. 6. Simulated abnormality on the right.

Nos. 7, 8. Simulated abnormality primarily on the left.

Nos. 9, 10. Simulated abnormality shifting from side to side when general disintegration was attempted.

situation, it would appear that the relationship between the type of abnormality and the signalled spasm is a most flexible one.

Experimental analysis of action current abnormalities. A series of attempts were made by the writer and Professor Travis

to duplicate the records of stutterers' action currents from the masseter muscles. In the first attempt both *Es* tried to duplicate the strain by which the muscles of the face appear to be forced into abnormal positions. Three things were attempted in these first records: (1) putting the abnormality on the right, (2) putting it on the left, (3) putting it on right and left in a generally dysintegrated fashion. The attempt ended in general failure to get action currents which in any way were like those of the stutterer. In the records of each, however, there were one or two areas where the left side seemed to have functioned independently of the right for a short time. Both *Es* were right handed but both concluded that the left side of the face was a little more active than the right.

In a second experiment the writer went through a period of training in which he attempted to develop ability to move the jaw muscles independently. A second series of records was taken. These were successful to the extent that a striking difference of intensity was produced when the attempt was made to use only the left side. The records were unsuccessful in that there was no production of differences on the right side and from side to side in attempted general dysintegration. However, some progress had been made.

In clinical practice the writer had been impressed often by the fact that the stutterer was unable to locate the area in which a definite feeling of strain appeared. Could it be that there is no strain? At least it gave an idea for a new attempt at duplicating the stutterer's masseter records.

During a period of training an attempt was made to do the following: (1) stutter by closing off the breath stream—the muscles of pharynx and the soft palate acting in a fashion akin to the gag reflex; (2) while maintaining a state of partial closure of the air stream to withdraw all effort from the muscles, in the attempt to keep the swallowing reflex from occurring; (3) to maintain the whole facial musculature in this state of balanced relaxation (the feeling of this state was not entirely one of relaxation as much as it was that akin to the standing on one's toes reaching for something that is just out of reach); (4) to

speak in this state. Subjectively, there appeared to be little surges which, only partially under control, were sensed in the musculature of the jaws and face and hence the masseters.

In Fig. 5, Nos. 6, 7, 8, 9, 10, is presented a series of records which were produced by the writer in the manner outlined above. No. 6 shows the abnormality appearing on the right, Nos. 7 and 8 show abnormalities on the left. Nos. 9 and 10 show abnormalities appearing on either side. These came from the attempts at a general dysintegration in which both sides were used in an unorganized manner.

If these records are compared with those from stutterers it can be seen that there is a close approximation to some of the records of the latter (Fig. 4). As has been mentioned, *E* felt semi-reflex surges or twitches when the pharyngeal, palatal, and facial musculatures were maintained in a state of relaxed and somewhat expectant instability. In addition to the feeling of reaching for something just out of reach while on tip-toes, two other illustrative descriptions come to mind. The first is that of maintaining one's balance on a horizontal pole while attempting to knock a similarly balanced opponent off the pole with a pillow. Another is the attempt to ride a log or a barrel in a swimming pool. The attempted action seems to be directed to keeping the way open for speech and still not to maintain tension by a setting of the muscles, as that would interfere with free articulation. There is a sense of doing what is best with a situation that may break down any moment, and when it does break down to recover with as little forced effort as possible. None of these describes the experience exactly; they are but subjective impressions.

If these data from the normal speaker give any index whatever of the condition in the stutterer, it would appear that the stutterer, as indicated by the action currents from the masseter muscles, is attempting during the stuttering block to use a speech mechanism which is responding in a definite manner either to lack of organized nerve impulses or to some more gross condition in the articulatory mechanism which constantly threatens and occasionally succeeds in breaking down the speech function.

V. Discussion.

Eye-Movements

From the data presented in the preceding section the following items concerning the eye-movements of two groups of stutterers, divided according to whether they did or did not stutter in the experimental situation, were noted: (1) in the four measures of eye-movements—mean fixations per line, mean duration of fixation, mean reading time per line, and mean regressions per line—the two groups were practically alike in the silent reading situation; (2) the values for the non-affected group in the oral reading situation tended to remain constant throughout the series; (3) the values for the affected group tended to vary quite widely from situation to situation; in reading with *E* the affected group gave as good or better indication of efficient eye-movements than did the non-affected group; in reading while alone and reading semi-memorized poetry a slight difference in favor of the non-affected group was evident; in ordinary reading, relaxed reading and reading difficult sounds the non-affected group was superior; (4) relaxed reading exhibited greatest inefficiency of eye-movements for both groups; (5) the reaction to reading with *E* was reversed in the two groups, when compared with their performances in ordinary reading; in the affected group the reaction was toward better eye-movements, and in the non-affected group the reaction was toward poorer eye-movements.

A question to be considered here is that of the relationship between these measures of eye-movement and the phenomenon of stuttering. One measure can be disposed of immediately. Anyone who has listened to an average stutterer has become aware of the fact that at the time the stuttering is present the rate of speaking may be slowed down a great deal. Obviously then the reading time per line would show a proportionate increase as the factor of stuttering entered to consume time. But what of the other measures?

In the study of eye-movements in normals during silent reading it has been pointed out by *Tinker* (17), *Walker* (21), *Judd* and *Buswell* (12) and *C. T. Gray* (8) that the type of material read,

the ability to comprehend, and the attitude with which the reading was done have effect on the measure of eye-movements. *Tinker* says, "There is much data to indicate that the nature of the oculomotor performance in reading is largely determined by central processes of perception and apprehension. In other words, eye-movement patterns do not cause but merely reflect efficient or poor reading performance." Judging from the ideas of such authorities, the relationship between efficient eye-movements and the central mental processes is that of control of the former by the latter. Difficult material or an analytical attitude in reading will cause an increase in the number of fixations, in the number of regressions and in the length of fixations, in addition to increasing the length of reading time.

Buswell (3) has traced the growth of the eye-voice span in reading from the lower grades up to high school. He found that the child beginning to read fixates the word being spoken and that as skill in reading is achieved the eyes tend to move farther and farther ahead of the voice until reading habits are set at about the time of entering high school. He found also that good readers have a much wider eye-voice span than do poor readers. His records show that the relationship between the voice and the eyes in oral reading is a very flexible one and that both are under the domination of the central processes. He also found that as *S* reads, the eye-voice span varies—if easy material is being read the span may be as many as 15 to 20 spaces. If an unknown word or a phrase of difficult content is encountered the span decreases; it may even disappear if the eyes fixate long enough on the word for the voice to catch up. In some cases the lead may be negative as the eyes make a regressive movement to tie a word in with what has gone before.

In the discussion thus far it has been pointed out that the eyes as observed in silent reading respond to the central mental processes. In oral reading the eyes respond similarly to the central processes, the relation of the eyes and voice depending upon the factors of perception and apprehension. The eye in reading is the exploratory agent of the mind, so to speak, and is guided through its routine of movements by the mind. Now what is the condition in the stutterer during oral reading?

In the stutterer the same three elements are in the situation but in changed relations. There is material to be comprehended, the eyes to be controlled and the vocal mechanism to be used. In the reading material used in this experimental study there was little which was difficult to comprehend. The unstable factor in this case was the vocal mechanism. If the eyes as the more independent member of the three behave in a manner which indicates dysintegration when difficulties are encountered by the central processes, is it not logical to believe that the same type of dysintegrated activity will occur if difficulty is encountered by the vocal mechanism?

As has been demonstrated by the investigators of silent reading, the eyes stop on a word which is difficult from the standpoint of comprehension. It is reasonable to believe that they can and will stop on a word that is recognized from past experience as likely to be associated with stuttering. In either case a long fixation would be the result. Again, if the eyes are proceeding with a normal lead over the voice and the vocal mechanism gets in difficulty, the tendency for the organism to eliminate the difficulty will cause the eyes to regress. If this occurs often, the great number of regressions noticed in the eye-movement records of stutterers will be found.

The occurrence of either or both of these two responses to words that are difficult, not from the standpoint of comprehension but of the act of being spoken, will result in a greater number of fixations per line. Keeping attention on the difficult word for a long period of time will cause long fixations, and regressive movements as mentioned above will result from the eyes returning to the place where progress is stopped.

The reflexive types of movements noted by *Jasper* and *Murray* (10) were present in some of the records obtained in this study. They appeared in some of the very long fixations in some Ss. However, it is thought that the changes in the measures of eye-movements noted in the data and the changes from situation to situation noted in the group in which stuttering appeared during the experimental situation were more often normal reactions of the eyes to the difficulty encountered by one of the three processes used in the reading act, namely, verbaliza-

tion. The latter process, the most unstable one, determines the degree of efficiency exhibited by the eyes in the experimental situation.

The variation, then, in measures of eye-movements from situation to situation is in all probability the result of failure of the vocal mechanism in the synergic activity of reading. The reasons for these variations will be treated in the following discussion of breathing and action currents from the masseter muscles. These physiological systems are more directly employed in the act of verbalization than are the eyes.

Breathing

From the work of *Skaggs* (16) it is learned that manifestations of breathing activity are varied by differences in mental attitude. He investigated states of relaxation, mental work, excitement and shock. In excitement the amplitude and rate of breathing were increased. *Negus* (14) outlines the flexible subordination of the breathing function to the immediate task of the individual. *Johnson* (11) and *Fletcher* (5, 6) have dealt with the emotional reactions of the stutterer to the speaking situation.

The data of this study show that forces inherent in the situation caused reactions in the breathing activity of the group affected by stuttering that are opposite in direction to those reported for normals, while the breathing habits of the non-affected group demonstrated the more normal flexible responses to the various situations.

In the silent reading situation the two groups were found to be approximately equal by all the measures applied in this study. Four situations may be considered as situations which elicited more stuttering in the affected group. These were ordinary reading, relaxed reading, reading difficult sounds, and propositional speaking. Performance was indicated in terms of the number of signalled spasms, the number of recorded abnormalities, and the amount of inefficiency indicated by unfavorable measures of function with wide variability from the mean.

In reading with *E* the most favorable response was made by the affected group in all measures applied. So favorable was the

response in this situation in all three experiments that the values obtained were often superior to those obtained in any situation for the non-affected group. The reaction in the latter group to reading with *E* was definitely unfavorable in most of the measures.

Apparently the nature of the various situations was an important factor in causing the observed differences. An empirical analysis of the experimental speaking situations in terms of the task and the history of the stutterer follows:

1. Ordinary reading.
 - a. A task often closely connected with the early history of stuttering in the individual.
 - b. The situation represents a long line of constant attempts (usually ending in failures) to participate in this particular activity in school life.
 - c. A strong amount of social responsibility is inherent in the situation.
 - d. The situation is pervaded with emotional feelings of embarrassment and frustration which have been associated with attempts to carry out this
2. Relaxed reading.
 - a. This situation has all of the factors concerned in ordinary reading plus two important additions.
 - b. Most stutterers reveal a history of being advised "to relax," "to speak more slowly," and "to be at ease." The advice was not effective in the past and in many cases the stutterer reacts unfavorably to such advice. The fact that he cannot do the apparently simple thing suggested by well meaning relatives and friends bothers him.
 - c. The attempt to alter consciously the synergic systems used in speaking calls attention to the speaking mechanism itself and to the manner in which it functions. In the altering of most physiological action, which has tended to take on the aspect of a bad habit, there is always the necessity of being satisfied with less efficiency for a period until the temporal sequence of events in the desired act is sufficiently perfected. The development of form in athletic activities offers excellent examples of this principle. The stutterer in attempting to alter consciously his habitual reactions very often has more difficulty than when he attempts to speak in his ordinary manner.
3. Reading difficult sounds.
 - a. Most stutterers believe that certain sounds cause them more difficulty than do others. *Bryngelson* (2), *Hendrickson* (9) and *Brown* (1) have found little correlation between any particular sounds and stuttering *per se* for stutterers as a group. *Brown* found that individual stutterers stutter more frequently in relation to certain sounds than they do in relation to others.
 - b. There are the same social responsibility, the same historical features of failure, the same emotional reactions in this situation as in the two preceding ones.
 - c. Stutterers report the presence of apprehensiveness as the eye perceives words containing the difficult sounds during the act of oral reading.

- d. The reading situation prevents the use of substitutions, thus cutting off one means of escape from the difficult sound.
4. Propositional speech.
 - a. This situation presents in general the same historical elements as the preceding situations.
 - b. The added social obligation of being responsible for the symbolic formulation as well as the verbal expression tends to complicate this particular situation.
 - c. The individual himself is responsible for the thought expressed.
5. Reading with *E*.
 - a. The social responsibility is divided. The knowledge that someone is there to "carry on" in case of difficulty is fully sensed by the stutterer. In a preliminary experiment for the study, two female stutterers were acting as *Ss*. Both had had a great amount of difficulty in four situations. When the time came to try reading with *E* he was engaged in instrument observation and adjustment. One of the stutterers was asked to read along with the other in lieu of *E*. Both *Ss* started to read, apparently with great confidence, and neither had a single spasm in the entire situation.
 - b. The history of such activity if there is any history, is one of success rather than one of a series of failures.
 - c. Visual and auditory cues are given by *E* who also sets the tempo, the phrasing and to a certain extent the emphasis.
6. Reading while alone.
 - a. The social responsibility has largely if not completely disappeared.
 - b. The usual history is one of success rather than failure as in the situation above. There are exceptions to this.
7. Reading semi-memorized and familiar poetry. The reaction to this situation was varied.
 - a. The content and entire thought-symbol pattern are familiar.
 - b. The individual is an interpreter of another rather than himself.
 - c. Any proclivity toward certain difficult sounds will tend to be expressed in this situation.
 - d. The attitude toward poetry itself may cause reaction to this situation.

From the foregoing analysis two important general factors stand out. (1) The mere act of social confrontation is a force that acts upon and changes the individual. Speech demands that the speaker take the spotlight. Stage fright in normal speakers may result in interesting physiological and behavioral manifestations. (2) The ontogenetic history in relation to stuttering increases susceptibility to dysintegration in certain types of situations.

When an individual neurophysiologically susceptible to breakdown in the speech function meets a situation in which the above factors appear, interaction between the elements in the situation

and the neurophysiological weakness will tend to result in stuttering.

In the data from the breathing experiment there is confirmation of this point of view. In ordinary reading, relaxed reading, reading difficult sounds, and propositional speaking, both factors are present to a high degree. The result in the affected group is lessened amplitude and prolonged duration of the breathing cycles. If there is more emotional reaction to situations in which stuttering occurs, the facts noted are in diametrical opposition to the effects of similar emotional situations upon the measures of breathing of normal speakers as noted by *Skaggs* and mentioned above.

The non-affected group respond in a more normal way to all situations except propositional speech where the amplitude for this group is decreased and the duration of inspiration is increased although duration of expiration did not increase for this group. In these three measures for this particular situation the records of the non-affected group tend to take on the typical picture of the affected group and the significant thing is that the majority of the non-affected group did stutter in this particular situation.

In those situations where the two factors of social confrontation and adverse ontogenetic history were minimized the responses of the affected groups as revealed by the various measures applied tended toward that of the non-affected group and of normal speakers.

The data on the frequency of breathing abnormalities show that the effects of these two general factors in the situations are expressed in abnormal physiological activity which has relation to stuttering and the speaking act.

This susceptibility of the organism to influences in the speaking situation strikes a hopeful note in the therapy of stuttering. The ability to confront difficult situations is capable of development. Reactions to the ontogenetic factors in the stutterer may be altered by getting him to adopt an objective point of view toward his speech disorder. It might be said that unless these two are given attention in the therapy, stabilization of the neurophysiological organization of the individual will, in a measure, be prevented from being effective.

Action Currents

What has been said about the experimental situations in the discussion of breathing applies to physiological expressions of stuttering in action currents from the masseter muscles. The same correspondence between the frequency of spasms with consequent appearance of abnormalities and changes in the speaking situation appear in the data of the action current experiment.

That part of the investigation in which records were made of attempts to duplicate abnormalities of action currents in stutterers suggests the nature of the condition in the masseter muscles at the time that the abnormalities appear. A definite technique is necessary to simulate successfully the action current abnormalities of stutterers. The essence of this technique is the maintenance of a type of balanced withdrawal of activity from the musculature under investigation. An effort must be made to sustain this balance between expected trouble and the continuity of speaking. When the trouble comes the reaction to it must be made in as delicate a manner as possible. All of these statements are from the standpoint of the normal speaker attempting to duplicate the records of stutterers.

The condition in the stutterer is not definitely known. The low general amplitude of stutterers' action currents plus the instantaneous expression of the abnormality suggest two possibilities. (1) The general state of cortical activity is such as to direct (perhaps under protest) relatively few impulses of low intensity into the musculature in question during the time that the stutterer is experiencing no observable difficulty. Dysorganization of motor lead may occur in the cortex, chaotic activity may arise, and the observed action current abnormality during spasm may result from such dysorganization. (2) From another point of view the stutterer, due to the two factors mentioned in the analysis of the speaking situations, may be in a state of general apprehension or of continual anticipation that difficulty will occur. His reaction to this may be the readiness state of balanced relaxation so conspicuous in the records as small-amplitude action currents. He may, so to speak, be riding down a narrow lane between success and failure in the speaking act.

When the spasm strikes, which in this way of thinking might be the mal-functioning of some of the grosser structures in the articulatory mechanism or the activation of a vegetative reflex under control of lower centers, the individual habitually acts in one of three ways: (1) by an immediate strong reaction of a disorganized kind which results in the type of abnormality that bears direct relation to the signalled overt spasm; (2) by temporary withdrawal of activity, which state is followed by a successful effort to break the spasm—this type would be indicated by the signal-spasm relation which shows that the signal preceded the appearance of the abnormality; (3) by withdrawal of activity until the spasm has passed by and is no longer active—this would result in the signalled spasm without recorded concomitant action current abnormality.

The data show that the relation between the signalled spasm and the occurrence of some type of abnormality is high. However, the occurrence of signalled spasms without temporally related physiological expression in abnormalities occur frequently enough to warrant some thought. Several reasons that may be suggested for this condition are: (1) the stutterer waits out the spasm as suggested above; (2) no abnormality is present in the peripheral structure, due to a block occurring centrally; (3) abnormality is not expressed in that part of the mechanism the action of which is under observation; (4) failure to record an abnormality accompanying an observed spasm may be due to failure of the apparatus employed in the recording; (5) no abnormality may have been present during the spasm; (6) *E* may have been deceived in signalling what he thought to be a spasm, but which in reality was a pause on the part of the stutterer.

VII. Summary. From the investigation of the frequency of appearance of abnormalities and changes in the measure of function of the movements of the eyes, of the action of the breathing mechanism, and the activity of the masseter muscles as indicated by action currents, in stutterers it was found that:

1. Changes in the measure of function of the eyes varied from situation to situation in stutterers who stuttered in the experi-

mental situation, while the measures tended to remain constant for stutterers who did not stutter in the experimental situation.

2. The influence of stuttering on measures of breathing was found to be opposite in nature to that expected in comparable breakdown in the normal speaker. Embarrassment and emotional reaction to speech difficulty seem to be expressed in a decreased amplitude and increased duration of breathing.

3. Frequency of abnormalities of breathing varied from situation to situation in the affected group. Relation to the signalled spasm was high in this group. The non-affected group showed abnormalities unrelated to overt spasms, except in propositional speaking, the one situation in which the majority of this group did stutter.

4. Frequency of action current abnormalities varied from situation to situation. A close relationship exists between the signalled spasms and the appearance on the records of action current abnormalities.

5. Successful duplication by a normal speaker of action current abnormalities as observed in the stutterer was possible by a definite technique.

VIII. Conclusions. The data seem to warrant the following conclusions:

1. The decrease in efficiency of eye-movements in stutterers during stuttering seems to be a reaction to difficulty present in one of three physiological mechanisms used in the speaking act, namely, verbalization.

2. Two general forces, the reaction to social confrontation and the ontogenetic factors surrounding the malady of stuttering, interact with the neurophysiologically susceptible organism of the stutterer and produce stuttering in those situations where the three are present to a sufficient degree.

3. Susceptibility of the stutterer to changes in the speaking situation is suggestive of the efficacy of a therapy which will increase his ability in social confrontation and develop within him a more objective point of view toward his disorder. Therapeutical measures of this sort may be necessary accompaniments of effort to stabilize the stutterer neurophysiologically. In some

cases such therapy might enable the individual to exert successfully that degree of stability which he possesses.

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A STUDY OF THE EXTENT OF DYSSYNERGIA OCCURRING DURING THE STUTTERING SPASM

by

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I. Introduction. Since the work of Halle (8) and Ten Cate (16) in the early part of the present century, the stuttering syndrome has been subjected to extensive experimental study. Most of this work has been directed to an analysis of the symptomatology of stuttering, in the belief that a thorough knowledge of the symptoms would throw valuable light on the nature of this disorder. Studies have been made of breathing, voice, gross laryngeal movements, masseter muscle activity, and eye movements separately, or of the relationship between two of these activities. It seemed desirable to attempt to get a composite picture of the spasm by recording simultaneously as many of these activities as possible. It was thought that such records would throw light on the following questions: (1) what is the temporal relationship between various symptoms of stuttering and the various parts of the stuttering spasm? (2) to what extent is any one symptom characteristic of the stuttering spasm? (3) how extensive is the dyssynergia that is presumed to exist during the stuttering spasm?

II. Analysis of the problem. A number of problems arose at the outset. In the first place, it was necessary to adopt some criterion of the occurrence of the stuttering spasm. It must be recognized that the overt spasm may not be identical with the 'essential' spasm in frequency of occurrence or in duration. The overt spasm, *i.e.*, the perceptible interruption of the speech rhythm, is conceived of as a complex reaction pattern in which incidental associated movements which are merely reactions to the spasm overlie neuromuscular disturbances that are charac-

teristic of the 'true' or 'essential' spasm. At present, however, there is no criterion of the occurrence of a 'true' spasm which is more reliable than the overt spasm. Determination of the overt spasm is, admittedly, subject to error. In the first place it is dependent upon the acuteness of *E*. In the present investigation, due to the limitation of space in the sound-insulated recording room, it was not feasible to use more than one *E*, who went through a training series in which his results were checked against the stutterer's own reports until a high degree of reliability in detecting the spasms had been attained. Even with the most highly trained *Es* however, reliability in indicating spasms of brief duration is invariably low. Consequently, in the present study, no spasms less than 500 ms. in duration have been included in the results.

The second problem in setting up the study was the determination of the activities to be recorded. Since as complete a picture of the stuttering spasm as possible was desired, it seemed advisable to record activities connected with three phases of the speech process: respiration, phonation, and articulation. For this purpose, records were made of respiratory movements of the upper thorax by means of a pneumograph placed at the level of the armpits and of the lower thorax by means of a pneumograph placed at the level of the xiphoid process¹; the sound wave was photographed as the best available index to laryngeal activity²; and electro-myograms were made of the activity of the facial muscles, principally the masseters, as representative of the activity of the articulatory mechanism³. In addition, it was thought desirable to attempt to investigate the possibility of dyssynergic activity of bilaterally paired muscle groups, since this would yield information on the extent to which unified control by the central nervous system of bilaterally paired muscle groups was disturbed during the stuttering spasm. For this purpose, records were made of the activity of the two sides of the lower thorax at the level of the floating ribs⁴; of homologous facial muscles; and

¹ Designated as Vertical Breathing records.

² Designated as Voice records.

³ Designated as Action Current records.

⁴ Designated as Horizontal Breathing records.

of the vertical and horizontal movements of the eyes⁵. The techniques available at present do not make practicable the study of isolated homologous speech muscles. However, a previous study (20) had established the presence of asymmetry in breathing curves taken from the two sides of the abdomen and it was felt that such records would give the best available evidence of dyssynergic activity of the lateral sides of the breathing mechanism.

In another previous study (19), dyssynergia had been observed in the activity of homologous facial muscles involved in articulation. In the present study, small surface electrodes placed over the respective masseter muscles were used to record this activity. While the resulting action current pattern is primarily from the masseter muscles, adjacent muscles such as the risorius, zygomaticus, and orbicularis oris have some effect. All of these muscles, however, are bilaterally paired, and differences found in the myograms from opposite sides of the face would be evidence of bilateral dyssynergia.

Records of vertical and horizontal movements of the eyes provided an opportunity to determine whether the neuromuscular disturbance presumed to be present during the stuttering spasm is sufficiently widespread to disturb the co-ordination of paired, bilaterally innervated muscle groups which are not part of the speech mechanism. Since the mechanisms for control of voluntary conjugate and disjunctive movements of the eyes are highly complex and are of comparatively recent development both phylogenetically and ontogenetically, it would seem logical to expect that an extensive neurological disturbance would reveal itself in some ocular dyssynergia.

At this point in the analysis of the problem there became apparent the necessity for careful definition of the 'symptoms' or 'evidences of dyssynergia' which were to be studied. Stuttering, as it is customarily defined, is an interruption of the normal rhythm of speech. In describing the symptoms of stuttering, we are not primarily interested in presenting various evidences of interruption of the speech processes. To show, for

⁵ Designated as Eye-Movement records.

example, that the processes of respiration and of phonation have been suspended, or prolonged, or clonically repeated, is merely to demonstrate that stuttering has taken place. This is little more than description. If symptomatological studies are to contribute to our understanding of the syndrome they must go beyond this point and attempt to reveal why the speech processes have been interrupted. This fact has been recognized in numerous studies. Those of *L. E. Travis* (19), *Bryngelson* (1), *V. Travis* (20), and *Murray* (15) are illustrative. These studies have described and analyzed what have been called variously 'inco-ordinations,' 'dissociations,' and 'dysintegrations.' In the present study, the term 'dyssynergia' is substituted because of its more general meaning. The use of this term simplifies reference to disturbances of muscular co-ordination in a system, such as the eyes, which is not an integral part of the speech mechanism. The term 'dysintegration' here is confined to the lack of integration between various parts of the speech mechanism, while the term 'asymmetry' or 'inco-ordination' will be used to designate a lack of co-ordination in the functioning of homologous structures.

The present study, then, is concerned with the dyssynergia occurring during the stuttering spasm. What is to be considered evidence of dyssynergia? For an answer to this question it is necessary to turn to the results of those previous studies in which the various activities here investigated have been dealt with separately.

Respiratory movements of the thorax during stuttering have been studied by *Halle* (8), *Ten Cate* (16), *Gutzmann* (7), *Fletcher* (4), *L. E. Travis* (17), *Fossler* (5), *V. Travis* (20), and others. All of these investigators agree that abnormalities of breathing accompany stuttering. Since, as *Fletcher* points out, there are as many varieties of breathing as there are varieties of stuttering, the list of the abnormalities which have been described is too long to quote here. It has been adequately summarized by *Fossler* (5). From this list the following abnormalities have been selected as evidence of dyssynergia in the activity of the mechanism of respiration:

1. Antagonism between the activity of upper and lower levels of the thorax, reported by *L. E. Travis* and *Fossler* (cf. Fig. 3).

2. Prolonged inspiration, occasionally accompanied by vocalization, reported by *Halle*, *L. E. Travis*, and *Fossler* (cf. Fig. 2).

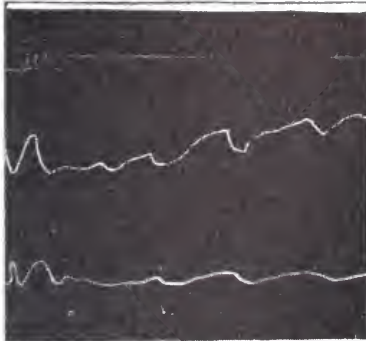


Fig. 1. Expiration interrupted by inspiration

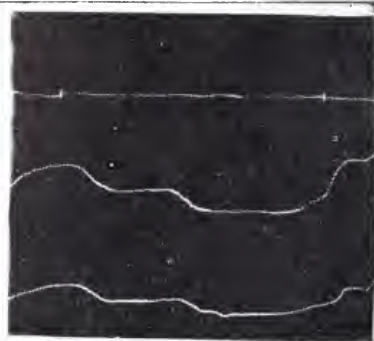


Fig. 2. Prolonged inspiration

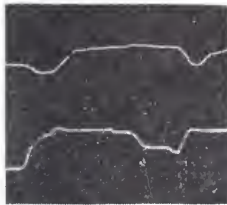


Fig. 3. Opposition



Fig. 4. Tonic block



Fig. 5. Clonic block

FIGS. 1-5. Typical breathing abnormalities. The lower line is from the lower thorax; the second line is from the upper thorax; the third line, where shown, signals the overt spasm. Downstrokes indicate inspiration.

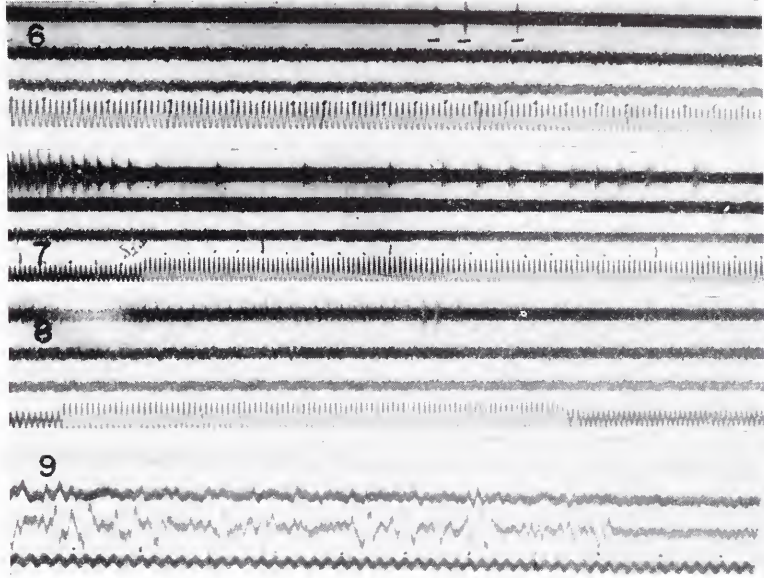
3. Inspiration broken into by expiration, or vice versa, reported by *Fletcher* and *Fossler* (cf. Fig. 1).

4. Clonic and tonic interruptions of expiration, reported by *Halle*, *Gutzmann*, *L. E. Travis*, and *Fossler* (cf. Figs. 4, 5).

5. Asymmetry in the activity of the lateral sides of the abdomen (reported by *L. Travis*).

Studies of vocal disturbances in stuttering have been made by *L. E. Travis* and *Bryngelson*. All these investigators report the following phenomena, which may be taken as evidence of dys-synergic activity of the intrinsic musculature of the larynx:

1. Tonal fixation and rigidity. This criterion could not be included in the present study because of limitations on the speed



FIGS. 6-8. Abnormalities in vocal tones. Fig. 6, single waves; Fig. 7, variation in length of consecutive waves; Fig. 8, abnormal tonal ending. Fig. 9 is a typical abnormal action current pattern. Upper line in each is record of voice; two middle lines, action currents from left and right sides of the face, respectively; lower line, time in .250 sec., designating also the spasm period.

of the recording film, necessitated by simultaneous photography of action currents on the same film.

2. Pathologic variations in form, extent, and length of consecutive waves (Fig. 7).

3. Isolated waves (Fig. 6).

4. Abnormal tonal attacks and endings (Fig. 8).

Action currents from homologous muscles of the face have been recorded by *L. E. Travis*, who finds in stutterers a number of abnormalities, all of which may be included under the follow-

ing head: asymmetry of pattern in action currents obtained from homologous muscle groups on opposite sides of the face (Fig. 9)

Studies of the eye-movements of stutterers have been made by *Jasper* (10), *Murray* (15), and *Jasper and Murray* (11). With the exception of a part of *Jasper's* work, all the observations presented have been of the eye-movements of stutterers in the reading situation. *Kelly* (14) has pointed out that, while there seems to be a common element in reading and speech disabilities, the two defects to a considerable extent show independent variability. For this reason, in the present study it was decided to eliminate the reading situation and photograph the activity of the eyes while they were fixated on a point. This eliminated the abnormalities of movement which might result solely from a reading disability and made it possible to study the effect of the stuttering spasm on the highly complex act of convergence. *Jasper and Murray* (11) studied eye-movements of stutterers in a reading situation; they report various types of nystagmus during the stuttering spasm. Since nystagmus is not characteristic of the eye-movements of normals during fixation (2; 3, p. 580), it is indicative of a disturbance of normal muscular co-ordination and thus is to be considered evidence of dyssynergia.

To summarize, in the present study the following are considered to be evidences of dyssynergia:

In the breathing records: (1) antagonism between the activity of the upper and lower levels of the thorax; (2) prolonged inspiration, especially when accompanied by phonation; (3) inspiration broken into by expiration, or vice versa; (4) clonic or tonic interruptions; (5) asymmetry in the activity of the lateral sides of the abdomen. In the voice records: (1) pathologic variations in the form, length, or intensity of consecutive waves; (2) isolated waves; (3) abnormal tonal attacks and endings. In the action current records: asymmetry of pattern in the action currents obtained from homologous muscle groups of the face. In the eye records: nystagmus.

III. Subjects. The Ss were stutterers in the speech clinic at the State University of Iowa. In the first series of records, 15 Ss were used. With the exception of two, they had been

under treatment for varying lengths of time and were thoroughly familiar with laboratory procedure. In the second series, 17 Ss were used, of which four had been included in the first series. Eight of these Ss had not been under treatment prior to the time the records were made and were not accustomed to laboratory procedure.

IV. Apparatus. The apparatus used to record breathing consisted of a Stoelting long-paper kymograph driven by a spring motor, four Sumner pneumographs, each of which was connected by rubber tubing to a Jacquet tambour, a Jacquet chronometer set to record time in units of $\frac{1}{5}$ sec., a mercury manometer used to equalize the air pressure in the pneumographs, and a specially designed chair. This chair (similar to that used by *V. Travis*, 20) had adjustable arms and a stable cross-piece perpendicular to the back. With *S* seated in the chair, one end of each pneumograph used to record breathing curves from the two sides of the thorax was fastened to the cross-piece in back and passed around one side of the thorax to attach to the opposite arm of the chair.

A standard Westinghouse oscillograph was used to record voice and action currents. One element was used for the voice, two for the action currents, and the fourth was activated by a General Radio Type 377-B low frequency oscillator, to provide a time-line of 250 ~. The voice was picked up by a Jenkins and Adair C6 condenser microphone with one additional stage of amplification. The apparatus used for the action currents was the same as that described by *Travis* (19). It consisted of two pairs of surface electrodes, each electrode being made of a thin brass strip, four cm. long and one cm. wide, covered with Canton flannel which was saturated with concentrated saline solution. The paired electrodes were fastened one cm. apart in a bakelite base. Two perfectly matched, non-interfering, resistance-coupled amplifiers were employed. The oscillograph elements connected to these amplifiers were adjusted to the identical sensitivity of .045 in. deflection per milliamper. The amplifying recording units had flat frequency-deflection curves between 90 and 900 c.p.s. for constant input voltage.

Records of eye-movements were obtained by means of the

Iowa eye-movement camera (12). Several modifications were made in this instrument to adapt it to the purposes of the present study. A third lens was added to the two eye lenses so that head-movements as well as eye-movements could be recorded. The head-movements were obtained by photographing the reflection from a small silver mirror held in the middle of *S*'s forehead by a specially constructed spectacle frame. Independent light sources were used for the eyes and head mirror. They consisted of three 50-candlepower automobile headlight bulbs, each incased in a brass tube with an opening 3 mm. in diameter, into which was fitted a cobalt blue filter. The time-line device and film drive on the original camera had to be dispensed with, since the motors could not be satisfactorily shielded from the action current set-up. The film was driven by a hand crank and a signal marker was mounted in the recording box so that a beam of light could be directed on both the vertical and horizontal films at their point of crossing. A pendular light interrupter also was mounted in the recording box to make it possible to determine from the record the relative positions of the eyes and head at given moments.

The signal circuit consisted of a storage battery and a key connected to the signal light in the eye-camera, to a signal magnet on the kymograph set-up, and to the oscillograph element which provided a time-line on the oscillograph film. When the signal key was depressed, simultaneous points were recorded on the two eye-films, on the kymograph record, and on the oscillograph film which was recording the voice and the action currents.

An auxiliary signal-circuit, consisting of a key and two dry-cell batteries, controlled a signal light over the oscillograph. This served as a starting and stopping signal for the oscillograph operator.

A crystal head-set with an additional stage of amplification was tapped into the action current lines to make possible a constant check on the action current set-up. The voice, action currents, and eye-movements were recorded on Eastman No. 1 35 mm. recording paper.

17. Procedure. Before each *S* was brought in, the entire

apparatus was checked. Male *S*s removed clothing to the waist-line; with female *S*s the pneumographs were adjusted over light clothing. The upper pneumograph was placed at the level of the armpits and the lower pneumograph at the level of the xiphoid process. The air pressure in these pneumographs was equalized by means of the mercury manometer. *S* then was seated in the special chair and the lateral pneumographs were adjusted at the level of the floating ribs. Air pressure in these pneumographs also was brought to the standard reading on the manometer. Each pneumograph was then connected to its respective tambour by means of rubber tubing.

The electrodes, saturated with saline solution, were then adjusted in identical positions with reference to the ear and angle of the jaw, over the belly of the masseter muscles. Leads to the action current amplifiers were connected to the electrodes. The electrode contacts and amplifier circuits were tested by means of the head-set. A second check was provided by observing the action current lines in the oscillograph mirror. The mirror was then removed from the oscillograph and the recording camera put in place.

The microphone was placed in position, the head-line bead adjusted, and *S* clamped in the head-rest. The eye and head lights were turned on. *S* was instructed to focus his eyes on a given spot, approximately 16 in. in front of him and 6 in. above the plane of the eyes. The lights were focused and the reflections from the head-line bead and from the corneas of the eyes were focused on the vertical and horizontal films.

The action current set-up was rechecked through the head-set and the breath recording apparatus was checked by making a very short trial record on the kymograph paper. The focus of the eyes was rechecked and the entire recording-signal circuit tested.

While these checks were being made, *S* was instructed as follows:

"Throughout this recording process, allow yourself to stutter normally. Make no attempt to avoid or inhibit the spasm. You must, at all times, keep your eyes fixated on the spot. I will soon speak a word and count to three. A moment after the count of three I want you to repeat the word I have spoken. Remember to keep your eyes constantly on the spot."

E then would say 'ready?' and the operators at the oscillograph, kymograph, and eye-camera would answer 'ready.' A spoken word served as the signal for starting the eye-camera film and the kymograph. Simultaneously, the oscillograph starting signal was given by pressing the key in the auxiliary signal circuit. A count of three was given and at each count the recording signal key was pressed, giving simultaneous identification points on all records. Following the count of three, *S* attempted to speak the word which *E* had pronounced. If stuttering occurred, the recording-signal key was held down for the duration of the overt spasm. Shortly after the end of the spasm, recording stopped and the apparatus was rechecked in preparation for the next trial.

If no spasms were obtained by this procedure on the first four or five trials, *S* was asked to use free propositional speech. The number of trials varied with each case, depending on such factors as length of spasm, *etc.* Efforts were made to keep the *Ss* entirely at ease, and the success of these efforts is attested to by the fact that some *Ss* who were least accustomed to laboratory procedure stuttered slightly, if at all, during the recording.

Two series of records were obtained. In the first, action currents, voice, and breathing records were made. In the second series eye-movements also were recorded.

VI. Results.

Frequency of occurrence of abnormalities studied. Tables I and II show, for the first and second series of records respectively, the frequency of occurrence of the various abnormalities studied, in terms of per cent of spasms in which records for the given activity were obtained. The following are the most significant facts to be drawn from these data: -

1. In only seven of the 15 cases in the first series does any given type of abnormality occur in all spasms. In the second series, nine of the 17 *Ss* show a given type of abnormality in every spasm recorded. That this figure might be lower if a larger number of spasms had been recorded for each individual is shown by the data for cases 4 and 5. In the second series,

both of these individuals reveal certain types of abnormality in every spasm recorded, yet in the first series in neither case did any given type of abnormality occur in all the spasms.

2. Correlations between the frequencies of occurrence in the

TABLE I. *Frequency of occurrence in Series I of various abnormalities studied in terms of per cent of spasms in which records were obtained for the given activity*

Case No.	Type of Abnormality			
	AC	V	VB	HB
1	31		100	0
2	100	63	38	0
3	47	74	82	12
4	0	25	75	0
5	33	100	100	0
6	45		91	0
7	87	100	100	0
8	80	80	60	0
9	60	0	25	0
10	20	71	86	0
11	91	83	100	0
12	33		100	0
13	75	62	13	0
14	0	100	50	0
15	8	46	46	0

TABLE II. *Frequency of occurrence in Series II of the various types of abnormality in terms of per cent of spasms in which records of the given activity were obtained*

Case No.	Type of Abnormality				
	AC	V	VB	HB	EM
4B	0	100	100	0	80
5B	100	71	100		100
10B	0	55	92	0	64
11B	75	83	100	0	50
11C	100	100	100	0	0
16	0	82	91	0	73
17			92	0	44
18	100	58	92	0	100
19	25	92	100	0	75
20	100	100	0	0	66
21	33	50	58	0	25
22	50	40	80	10	78
23	25	25	75	0	100
24	33	50	50	0	0
25			33	0	0
26	78	61	100	0	76
27	17	65			17
28	64	71			8

various types of abnormality show no statistically significant relationship. The actual intercorrelations are ⁶:

Series I		
	r	PE _r
AC and V	.18	.19
AC and VB	— .01	.18
V and VB	.68	.11

Series II		
AC and V	— .04	.19
AC and VB	.18	.19
AC and EM	.25	.17
V and VB	.47	.16
V and EM	.20	.19
VB and EM	.28	.17

Temporal relationship of the various abnormalities studied to the overt spasm. Tables III and IV show, for the first and second series respectively, the temporal relationship of the various types of abnormality to the overt spasm, in terms of the actual number of abnormalities recorded. The most significant facts contained in these data are:

1. Sixty-nine per cent of all abnormalities in the first series occur only during the overt spasm. In the second series, this percentage is 71. Conversely, 31 per cent and 29 per cent respectively of all abnormalities occur at a period other than the overt spasm.

2. Voice and Vertical Breathing abnormalities show the highest temporal correlation with the overt spasm, since a larger percentage of these abnormalities occur during the overt spasm

⁶These correlations were computed by the rank-order method, using the formula:

$$\rho = 1 - \frac{6\sum D^2}{N(N^2 - 1)}$$

They were translated into a product-moment r by means of the table given by Garrett (6, p. 192).

The formula for PE_r is:

$$PE_r = \frac{.7063(1 - r^2)}{\sqrt{N}}$$

and at no other time⁷. The actual percentages of the various abnormalities occurring only during the overt spasm are:

Series I		Series II	
AC	52%	AC	32%
V	77	V	94
VB	75	VB	93
HB		HB	
		EM	50

TABLE III. *The temporal relationship of the various abnormalities to the overt spasm, in terms of the actual number of abnormalities recorded in Series I*

Type of record	Time of Occurrence Relative to the Overt Spasm							Total
	B	D	A	BD	DA	BA	BDA	
AC	6	33	1	7	7	2	7	63
V	2	45	1	5	4	1	0	58
VB	0	66	0	12	3	0	7	88
HB	0	2	0	0	0	0	0	2
Totals	8	146	2	24	14	3	14	211

In Tables III and IV the time categories are discrete. For example, under the category BDA are tabulated only the number of abnormalities that persisted throughout the periods before, during, and after the overt spasm.

TABLE IV. *The temporal relationship, for Series II, of the various abnormalities to the overt spasm, in terms of the actual number of abnormalities recorded**

Type of record	Time of Occurrence Relative to the Overt Spasm							Total
	B	D	A	BD	DA	BA	BDA	
AC	3	23	1	5	15	3	21	71
V	1	90	3	1	1		1	97
VB		113		7			1	121
HB			1					1
EM	5	46	1	13	10	1	16	92
Totals	9	272	6	26	26	4	39	382

* See legend, Table III.

The extent of dyssynergia occurring during the overt spasm. Tables V and VI show, for the first and second series of records respectively, the number of activities giving evidence of dyssynergia during the overt spasm. The most significant facts contained in these data are:

1. Overt spasms may occur without evidence of any of the

⁷ Data are not given for HB abnormalities, since such abnormalities occur in only three instances.

TABLE V. *Extent of dyssynergia in Series I, in terms of per cent of spasms for which complete records were obtained*

Case No.	No. of Activities Showing Evidence of Dyssynergia				
	0	1	2	3	4
2	0	38	4	38	0
3	0	12	76	12	0
4	25	50	25	0	0
5	0	17	50	33	0
7	0	0	25	75	0
8	0	20	40	40	0
9	50	50	0	0	0
10	8	17	58	17	0
11	0	10	10	80	0
13	27	13	47	13	0
14	0	0	100	0	0
15	32	36	32	0	0

In the cases omitted, satisfactory simultaneous records of all activities were not obtained.

TABLE VI. *Extent of dyssynergia in Series II, in terms of per cent of spasms in which complete records were obtained*

	No. of Activities Showing Evidence of Dyssynergia					
Case No.	0	1	2	3	4	5
4B	0	0	50	50	0	0
10B	0	17	66	17	0	0
11B	0	0	0	34	66	0
11C	0	0	0	100	0	0
16	0	0	45	55	0	0
18	0	0	0	55	45	0
19	0	0	27	55	18	0
20	0	0	100	0	0	0
21	0	50	33	17	0	0
22	0	22	45	22	11	0
23	0	34	17	33	16	0
24	17	34	49	0	0	0
26	0	0	19	38	43	0

abnormalities being studied. This is true of four of 12 cases in Series I and of one of 13 cases in Series II.

2. The dyssynergia occurring during the overt spasm may be strictly limited in extent. In seven of 12 cases in Series I, and in four of 13 cases in Series II, at least 20 per cent of the spasms show evidences of dyssynergia in not more than one of the activities recorded.

3. In the majority of cases, the dyssynergia most frequently extends to two or three of the activities recorded.

4. Comparison of the data from Series I and II (Tables V and VI respectively), will show that as the number of activities

recorded is increased, the number of cases in which no abnormalities are detected during the overt spasm decreases.

Qualitative analysis of the nature of the dyssynergia occurring during the overt spasm. The marked variability from individual to individual, and even from spasm to spasm in the same individual, makes impossible a complete qualitative description of the various forms of dyssynergia which occurred. Qualitative analysis may, however, be of theoretical importance and may serve to suggest further problems. The most important of these follow:

1. Action current abnormalities. Action current records obtained during uncontrolled voluntary activity, from surface electrodes placed over a muscle mass, are difficult to interpret. With surface electrodes placed over the masseters, as in the present instance, records are affected in unknown manner and extent by the activity of adjacent muscles, such as the zygomaticus, risorius and orbicularis oris. The results must be interpreted cautiously. Tables III and IV show that action current abnormalities occur in every possible temporal relationship to the overt spasm. Twenty-one per cent of all action current abnormalities persist throughout the entire record—before, during, and after the spasm. In two instances in each series, action current abnormalities occur only after the overt spasm; also, in two instances in each series, the abnormalities occur before and after, but not during, the spasm. In these cases there seems to be an inverse relationship between the action current abnormality and the overt spasm.

2. Sound-wave abnormalities. The records reveal no direct evidence of the cause or significance of the sound-wave abnormalities studied. For example, the single waves, or 'vibration couplets,' reported by previous investigators (1, 18), occur in all but 12 of the cases and constitute approximately one-third of the vocal abnormalities recorded, yet they bear no constant relationship to any other type of abnormality. They may occur during inspiration or expiration, or during opposition in the activity of the upper and lower levels of the thorax. The sound waves are an inadequate index to the activity of the larynx during stutter-

ing, because they give no indication of what is occurring in the voiceless tonic blocks which constitute a majority of the spasms.

3. Abnormalities of breathing. The most frequent type of breathing abnormality is a tonic block during expiration, which constitutes 55 per cent of all breathing abnormalities. Oppositions between the upper and lower thorax constitute 12 per cent of all breathing abnormalities and occur in records of nine of the total of 28 individuals. In only 12 of the total of 27 instances of opposition do action current abnormalities occur simultaneously with the breathing abnormality. In eight of 11 instances in Series II eye-movement abnormalities occur simultaneously with the opposition.

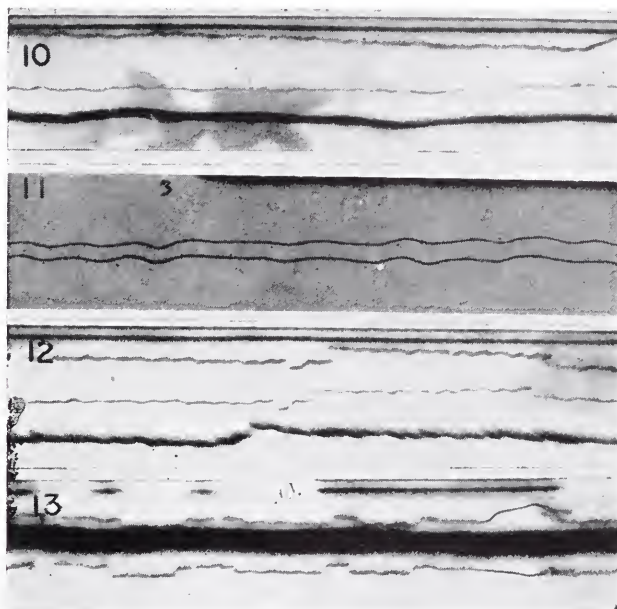
4. Eye-movement abnormalities. Four types of abnormal activity occur in the eye-movement records. In 23 instances, or in 10 of the 17 cases, the degree of convergence of the eyes increased (Fig. 10). In 14 instances, or in four of the 17 cases, the eyes diverge from the fixation position (Fig. 11). In 53 instances from 11 cases, conjugate nystagmus occurs, with the two eyes making co-ordinated movements to the right or left of the fixation position (Fig. 12). There are two instances of dissociated nystagmus in which the two eyes move dissimilarly (Fig. 13).

In view of the fact that so little is known of the neurophysiology of eye-movements, the significance of these movements is not clear. One may, however, hazard speculations. It generally has been agreed that a separate center for convergence must be assumed (3, p. 288; 9). This center is thought to lie in Perlia's nucleus. It would seem logical to conclude that, where the degree of convergence increases, the activity already in progress in this center during fixation is increased. The case would then be one of facilitation rather than dysintegration. In instances of divergence it may be assumed that activity of the convergence center is inhibited, since divergence is commonly thought to be relaxation of convergence.

It also has been rather generally held that a center exists for control of conjugate lateral movements (3, p. 288; 9). This is thought to lie oral and ventral to the sixth nucleus. Instances of conjugate lateral nystagmus seem to indicate that activity in this

center is brought about and supersedes the activity of the convergence center.

Instances of dissociated nystagmus are too few to warrant much attention. They seem to indicate a breakdown in the



FIGS. 10-13. Typical eye-movement abnormalities. Fig. 10, convergence; 11, divergence; 12, conjugate lateral nystagmus and convergence; 13, dissociated nystagmus following conjugate nystagmus. Upper line, signal for overt spasm; lower line in Figs. 10 and 12 and heavy line in Fig. 13 show head movements. The two light lines of each record show eye-movements.

control exercised by higher centers and a regression to the older level of monocular independence.

VII. Summary and conclusions. From a study of simultaneous records of the respiratory activity of the upper and lower thorax, of the lateral sides of the thorax, of the vocal tones, of the action currents from homologous facial muscles, and of vertical and horizontal eye-movements, the following results were obtained:

1. In approximately one-half of the cases no one of the types of abnormality studied occurs during all of the overt spasms.

2. Approximately one-third of all abnormalities recorded are not coincident with the overt spasm.

3. Voice and breathing abnormalities bear the highest temporal correlation to the overt spasm.

4. There is no statistically significant relationship between the frequency of occurrence of any two of the types of abnormality studied.

5. In approximately 30 per cent of the spasms recorded, evidence of dyssynergia is found in no more than one of the activities studied.

6. No consistent effect of the spasm on the activity of bilaterally innervated homologous muscle groups is observable.

From the above facts, and from a qualitative analysis of the abnormalities recorded, the following conclusions may be drawn:

1. There is no significant relationship between the various types of abnormality studied.

2. The relationship between the overt spasm and the various types of abnormality studied is not consistent.

3. The dyssynergia occurring during the spasm may be strictly limited in extent.

4. Since overt spasms occur in a number of cases without evidence of any of the abnormalities included in this study, and since in approximately one-half of the cases no type of abnormality occurs in all spasms, it may be concluded that in these cases no one of the types of abnormality can be considered an essential symptom of the true spasm.

5. The larger the number of activities recorded, the smaller is the number of instances in which no abnormality is detected during the overt spasm.

6. For certain individuals, the relationship between a given type of abnormality and the overt spasm is practically perfect.

The lack of relationship between recorded abnormalities and the clinically observed spasm may be explained on one of the following bases:

1. All stuttering spasms may not have been detected clinically.

2. The dyssynergia may not have expressed itself in a form, or to a degree, such that the apparatus used could detect it.

3. The dyssynergia may have occurred in mechanisms other than those under experimental control.

4. It is possible that stuttering may occur without any detectable accompanying neuromuscular inco-ordinations.

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AN ELECTROMYOGRAPHIC STUDY WITH RESPECT
TO SPEED OF MOVEMENT AND LATENCY,
DISPARATE AND RECIPROCAL
INNERVATION, ATTENTION
AND RELAXATION

by

BASU KUMAR BAGCHI

I. Introduction. Recent advances in electrophysiology have made it possible to interpret the anatomical and physiological bases of certain psychological processes. Particularly has the study of the response characteristics of single receptors and nerve fibers added to our knowledge of sensation and movement (3, 6, 16).

The greater number of such studies were made on animals where the anatomical factors were known and controlled, but where the psychological processes were not evaluated. Recently, action current studies have been made of intact human beings in an attempt to correlate physiological and psychological processes (9, 10, 14). There are two great problems in the psychophysical complex. One is: what are the underlying neurophysiological processes subserving psychological processes? The other is: how may physiological processes be affected by mental activity? The present study was set up in relation to both of these problems. Specifically, it concerns itself with the following: (1) the relationship between speed of movement and action current latency under different conditions; (2) the temporal and synergic factors in reciprocal innervation of antagonistic muscles (biceps and triceps); (3) disparate innervation of the two heads of the biceps; (4) possible sources of passive movement discharges; (5) action current frequency in attention and imaging; (6) post-relaxation latency in voluntary movement.

II. Apparatus and procedure. The recording apparatus has

been described in full by *Travis* and *Dorsey* (24). Briefly, it consisted of two three-stage resistance-coupled amplifiers, a Westinghouse oscillograph (with four elements), a General Radio low-frequency oscillator, and a signal circuit. Recording was done by a special photographic unit carrying 35 mm. sensitized paper. Needle electrodes made of 20-gauge platinum rhodium were imbedded in the muscle, about 1 cm. deep and from .8 to 1.7 cm. apart. Special precaution was taken by way of sterilization before insertion and at conclusion of the experiment. Except for the very tips, the electrodes, including the base which rested on the skin, were baked in bakelite varnish for the purpose of insulation. These electrodes were found more suitable for picking up fine changes in the muscle fibers within a strictly localized area than the large pad electrodes placed on the surface of the skin. Furthermore, the electrode points were always in the body fluid, and did not incur the risk of becoming dry and thus interfering with conduction by producing changes in resistance.

The action current or electrical potential generated in the muscle was fed by the input leads into the amplifier¹ which activated the oscillograph string supported in a strong electro-magnetic field. A beam of light falling on a small mirror mounted on the string, which has a fixed tension, was reflected on the sensitized paper. Any oscillation of the string-mirror, indicating disturbance in the electro-magnetic field due to the generation of electrical potential in the muscle, produced corresponding oscillation of light on the paper. Two elements of the oscillograph were used for recording action currents from two muscle groups or two distinct parts of the same muscle group. The third element gave the 1000 ~ (ms.) time-line as generated from the oscillator. The fourth element recorded the signal.

A pair of earphones was placed in a special vacuum tube circuit with the two amplifiers so that *E* could hear distinctly the action current discharges from either of the muscles. This device proved to be of particular benefit in as much as it gave

¹ An electric potential of one microvolt at the input of the amplifier at 400 ~ gives a diphasic deflection of approximately 4.25 mm. on the record.

warning of preliminary tension discharges which were disturbing in latency studies. In the event of such discharges an adjustment of the position of the limb was made before photography. Secondly, the device was found indispensable to signal the arrival and disappearance of single motor unit discharges during experiments on attention and imaging. Thirdly, it served as a valuable check on photographing as to the activation of antagonistic muscles and discharges in passive movement.

In order to reach the most active center of the muscle, its motor point was found by the uni-polar method of stimulation (*Howell*). A condenser (2 mfd) was by the turning of a switch discharged on the skin of the respective muscles. The large, inactive electrode (zinc, covered with Canton flannel which was soaked in salt solution) was fastened across the wrist of *S* with rubber bands. The small, active electrode was moved about on the muscle until the most appreciable twitch was found after exploration in the distal-proximal and transverse directions. The voltage was adjustable from 50 to over 100, depending on the skin resistance of *S*. For finer adjustment the voltage was reduced until only one of the points of the muscle gave a barely noticeable twitch. This was supposed to indicate the location of the entrance of the motor nerves into the muscle (*Howell*). The long and short heads of the biceps were found to have separate motor points.

The needle electrodes were inserted vertically into the muscle mass at the determined motor point and held firmly in place by adhesive tape (Fig. 1). Except for the pricking sensation at the time the electrodes were inserted no actual pain was experienced by the *Ss* during two hours of experimentation. *S* lay on a cot with his right arm placed horizontally at an angle of about 30° with his body on the radius-board of a specially designed arm-arc (Fig. 2). This radius-board was made of six-ply wood to insure firmness and yet lightness when raised or lowered along the arc. Its dimensions were 25 in. \times $4\frac{1}{4}$ in. \times $\frac{1}{4}$ in. One end of the radius-board was hinged to a base-board while the other end was left free to move between the two parallel strips of the arc. The vaulting arc, the slanting board and the permanent

horizontal board were attached as one piece to a vertical block of wood (3.5 ft. x 3 in. x $3\frac{3}{8}$ in.) and could be fastened to it at any position with a large blunt-end screw. This arrangement

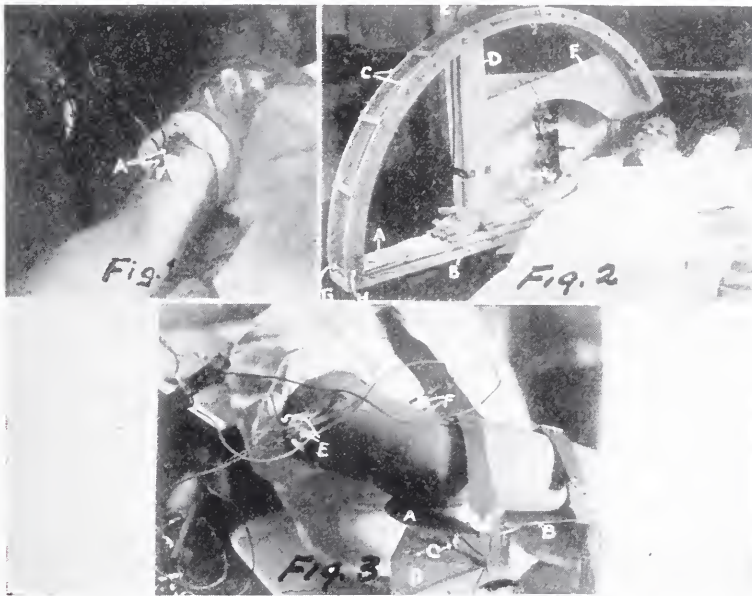


FIG. 1. Needle electrodes in the biceps. A=electrode bases made to stand firm and erect on the arm with the help of adhesive tape.

FIG. 2. The arm-arc. A=radius-board; B=base-board; C=two parallel strips of the arm-arc; D=adjustable vertical board; E=wooden stand; F=slanting board; G=cross-bar (metal), fitted with metal sleeves at both ends, springs inside, to keep sleeves pressed against parallel strips of the arc; H=contact points at zero to 5° , 1° apart, then at every 5° . When arm is raised, contact is broken at 0° .

FIG. 3. Disc-apparatus. A=4-in. iron disc; B=projecting piece of iron attached to A; C=adjustable metal shaft, 3 in. x $\frac{1}{2}$ in., around which disc rotates horizontally, clockwise or counter-clockwise; shaft is in line with axis of elbow bone. D=wooden block to which shaft is fixed, flat base clamped to firm support; E=electrodes in triceps; F=electrodes in biceps.

was necessary for adjusting the height of the radius-board to the outstretched arm of S, to secure ease and prevent any tension in the upper arm. The elbow (medial epicondyle) of S was level with the hinge of the radius-board, on which his forearm was laid flat and strapped at three places—the fingers, the wrist, and

two inches distal to the elbow crease. In moving his forearm up and down with the elbow as a fulcrum, *S* moved the radius-board up and down. A metal cross-bar at the far end of the radius-board came in contact with the degree marks on both parallel strips of the arm-arc. Over both cylindrical ends of this metal cross-bar were fitted two metal sleeves with inner springs, which kept them pressed against the parallel arcs. On the parallel strips there were six 1° marks, including the 0° mark, from horizontal up, followed by 29 5° marks on the circumference to the other side of the arc. The degree marks were made with reference to the hinge of the radius-board as the center. Both sides of the arc were in the signal circuit which finally was connected with the oscillograph element. This arrangement gave a record of the amount of elevation of the forearm, in degrees, and the speed with which it was made, in ms.

Since in a study of action current latency the first break is important, the apparatus was arranged so that there was no mechanical lag when the overt movement was made. A screw which was attached vertically to the metal cross-bar was allowed to rest on a metal strip fastened to the base-board. The metal strip was connected to one side of the signal circuit, with the metal cross-bar connected to the other side, touching the 0° mark on one of the parallel arc-strips. The 0° mark on the other parallel strip was unnecessary and hence electrically dead. When the radius-board was at 0° , lying on the base-board, the metal bar at its end was in make-contact. The instant the radius-board was lifted the screw, firmly connected with the bar, came up with it and the contact was broken. Then the 1 contact was made and broken on both sides of the parallel arc, then the 2 contact and so on upwards to the end of the movement.

The forearm was strapped in such a way that there was no lateral play and yet it could be raised easily. To permit this, the horizontal board was planed out and padded where the elbow rested, and a part of the radius-board was cut away between the two hinges and smoothed so that the arm could fit snugly and move up and down freely. The right upper arm, carrying the electrodes, was left entirely free in all instances.

S was given a few practice trials to get the proper mental set and kinaesthetic preparation for three speeds of movement—fast, medium, and slow—which were used throughout the experiment. He was asked to relax as much as possible, and at the signal (turning of the camera), to raise his arm at the elbow. Any tension discharges due to over-anticipation of the signal were detected by the earphones and *S* was told about them and asked to assume a more relaxed attitude before and at the time of responding. Certain preliminary training in this regard was given to induce habituation. This attitude of relaxation was found to be absolutely essential in the entire study.

The reason for using three speeds, fast, medium, and slow, and for assigning 20 to 59 ms. per degree for fast speed, 60 to 99 ms. for medium speed, and over 100 ms. for slow speed in anti-gravity movement, was the existence of a tendency for the speeds to fall within those ranges when *S* was instructed to move his arm at the respective rates. As for the slow speed and its subdivisions, the classification was arbitrary and made simply for convenient grouping.

In another series of experiments a disc-apparatus was used (Fig. 3). The disc-apparatus consisted of a thin, rigid iron disc, 4 in. in diameter. To it was attached a thin metal strip, $4\frac{1}{2}$ in. wide and projecting three inches beyond the margin of the disc. Below the disc's center was attached an ordinary rheostat and the whole piece (the disc and the rheostat) rotated horizontally clockwise or counter-clockwise on a flexible arm of an adjustable round metal shaft (3 in. x $\frac{1}{2}$ in.). This shaft was driven vertically into a block of wood (4 in. x 4 in. x 5 in.) and held in place at any angle to the block by a large screw. The shaft came up through the center of the disc, extending slightly above the disc's upper surface. A wire was wound across the edge of the circular non-conductor fiber-strip of the rheostat at measured angular distances from the center of the shaft. This wire and the metal shaft with its arm were in the signal circuit. The moment the disc started to rotate the contact was broken. In clockwise direction the contacts were at 0° , 10° , 20° , and 25° ; in counter-clockwise direction they were at 0° , 20° , and 45° . The block of

wood supporting the disc was in turn supported on a very heavy adjustable iron stand. *S* sat in a chair, right forearm resting on a light piece of fiber-wood (8 in. x. 4 in.) which lay flat on the disc and its projection. The axis of his elbow was in line with the vertical shaft. His forearm was strapped to the disc at two places, 1 in. and 6 in. respectively, proximal to the wrist. If the forearm was to be moved horizontally clockwise (making triceps active) it was placed at an angle of 45° to his upper arm. If counter-clockwise movements were desired (making biceps active), the forearm was placed at an angle of 170° to the upper arm. For the clockwise and counter-clockwise movements the proper adjustments were made between the shaft and block of wood. With this disc arrangement the muscle work was done against a minimum of friction and weight.

Eleven *S*'s were used. Two of them served twice, and one six times; 1279 records were read. Latencies of the leading muscle, or the leading head of the same muscle group, have been correlated with speed.

III. Data and discussion.

Speed and latency. *Adrian* (2), *Richter* (19) and *Travis* and *Lindsley* (25) have found that there is an increase in frequency of action currents with increase in intensity of muscular contraction. Speed of contraction was not measured by any of these workers. The importance of speed of sensory stimulation in the matter of initiation of nerve impulses was, however, early pointed out by *Adrian* (1). *Matthæus* (16) showed the accelerating effect on frequency of rapid loading of the single cutaneous receptor of a frog. *Hathaway* (8) recorded action current latency for the biceps and found 58 sigma the average value of quick contraction. But the speed factor was not objectively controlled. As far as we are aware, this factor has not been reported in studies of electromyographic latencies.

Latency is defined as the interval between the onset of action currents in a muscle group, and the overt muscle work which this muscle group performs in moving the limb to which it is attached from a position of rest. The beginning of this actual muscle

work is indicated by a break in the signal line (Fig. 4). The speed at which this is done has a direct effect on the length of the latent period.

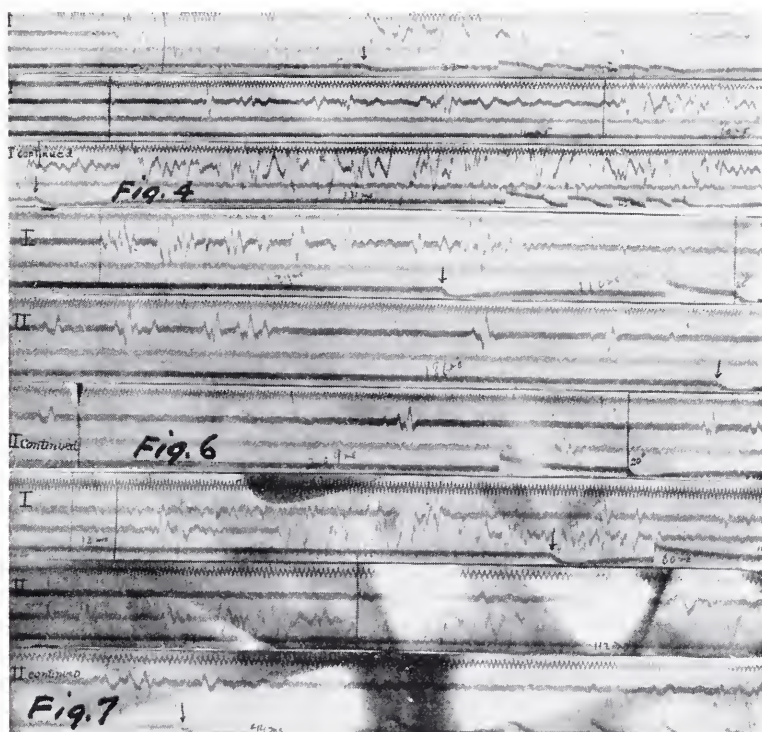


FIG. 4. I. Action current latency for biceps and triceps in fast voluntary movement of forearm from horizontal upwards on arm-arc against gravity. 1000 ~ time-line at top. Biceps represented by second line from top, triceps the third line, and signal the fourth line. First break signal at 0° is marked by arrow on signal line, indicating beginning of overt movement upwards; five other break marks represent one degree elevation of forearm; sixth break is 10° elevation. Latency of biceps is duration of action current from onset (left of record) to the first break (68 ms.). Interval between first and second breaks represents speed (37 ms. per degree) of raising of hand, from 0° . Note lag of triceps by 18 ms., also its low amplitude action currents in the latent period and its large action currents after 0° , indicating its full cooperation in the voluntary movement from that moment on.

II and III. Action current latency for biceps and triceps in slow movement of the forearm. Speed between 0° and 1° was 131 ms., biceps latency, 200 ms. (140 plus 60 ms.), triceps, 60 ms. Note that the latency is longer than in I and that the action currents are smaller, especially in latent period. Lines and break arrangement are same as in I.

FIG. 6. 1. Action current latency of biceps in fast counter-clockwise movement on horizontal disc. Arrow at break and beginning of overt movement. Speed between 0° and 20° , 110 ms., i.e., 5.5 ms. per degree; latency, 139 ms. Four lines from top down: time, biceps, triceps, signal. The biceps leads; no triceps latency. Size and amount of biceps and triceps action currents smaller here than in Fig. 4, 1; triceps delays in cooperating.

II and III. Action current latency for biceps in slow counter-clockwise movement. Note that latency is longer than in I and motor units involved are less in number. Some action currents in triceps.

FIG. 7. 1. Action current latency for biceps and triceps in fast clockwise movement on disc-apparatus. Time-line at top. Next three lines, respectively, are biceps, triceps, and signal. First break signal (overt movement) at arrow; second break represents 10 degrees, speed being 60 ms., i.e., 6 ms. per degree. Triceps more active than biceps, leading latter by 12 ms. and having latency of 129 ms. Size and amount of action currents smaller here than in Fig. 4, 1. Rhythmical tension discharges in biceps; other disturbances on the line.

II and III. Action current latency for biceps and triceps in movement of forearm from 75° down, with gravity, on the arm-arc. Break at arrow. Note the lead of triceps over biceps in latent period and co-operation of biceps. Lines same as in Fig. 4, 1. First break at 75° ; second at 70° .

Fig. 5 shows the average latency values plotted against speed of movement (ms. per degree). An examination of the figure will show this relationship: the faster the speed the shorter the latency, and, up to a certain point, the slower the speed the longer the latency.

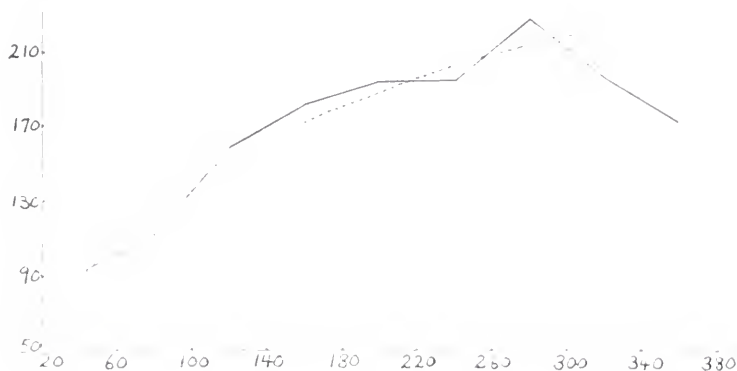


FIG. 5. The relationship between speed of movement and action current latency for the biceps in movement of the right forearm from horizontal position upwards on the arm-arc. Latency considered from the leading head of the biceps. Speed recorded between 0° and 1° . $N=318$; ordinate=average latency in ms.; abscissa=speed in ms. per degree. Solid line, observed curve; dotted line, the logarithmic curve.

These data were fitted to a logarithmic curve (Fig. 5) by the method of least squares (11), utilizing the values of six average latencies (Y) on six mid-points of class intervals of speed (X). Pearson's formula for the chi-square function then was applied in order to obtain the P (probability) of the least fit. The calculated chi-square value was 2.920, giving $P=.70$. This means that in 70 out of 100 trials we would obtain a fit worse than that obtained here. Hence the actual fit is a good one. P value of .2 or more is considered a good fit.

If we adopted all nine latency values, chi-square would have been 13.928 and P would have been .082. This would not have been a good fit. But in as much as the last three average latencies at the slowest speeds were based on a very few records we were justified in discarding them.

In order to compare the speed-latency relationship in the exercise of muscles against gravity, weight of the radius-board and arm, and friction of the arm-arc attachment, with the same relationship when these factors were present in a minimal degree, the experiments with the disc-apparatus were undertaken. There was slight inertia of the disc and insignificant friction in contact points; essentially there was only the weight of the arm moving horizontally. The results are shown in Figs. 6, 7, 8, and 9.

For a further comparison, the friction factor was entirely eliminated by the following set-up. The radius-board was lifted and through an opening in its base the forearm of S was placed and allowed to rest on a metal strip laid flat and fixed on the base-board at 0° . A metal bangle, padded inside, was fitted tightly over a region near S 's wrist. At the lower end of the bangle was soldered a tiny metal strip in the form of an arc, insulated except for the tip. This arc represented 0° to 5° , from tip to soldered point, its center being the mid-point between the two hinges where the elbow rested. The bangle and the horizontally fixed metal strip were in the signal circuit. When the arm was down and the metal bangle rested on the metal strip, the small metal arc hung in a hole in the base-board. The moment the arm was raised the contact was broken, and when the arm was raised 5° , the contact of the uninsulated tip

of the arc with the metal strip was again made and broken. Position of the bangle on the wrist was not determined by length of wrist but by the permanent distance between the point where

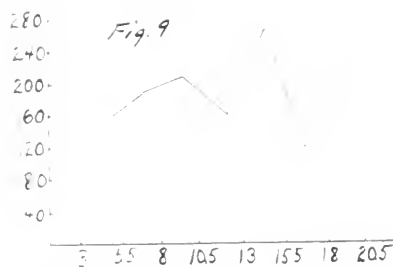
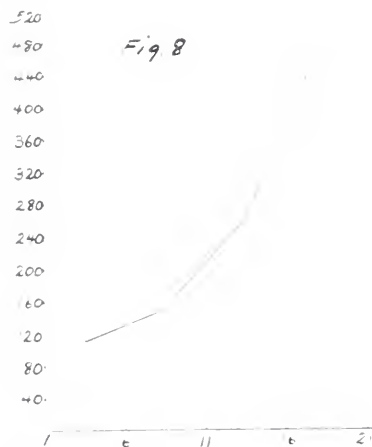


FIG. 8. Relationship between speed and action current latency in horizontal clockwise movement of right forearm on disc-apparatus. Leading activity from the triceps. Speed calculated between 0° and 10° . $N=33$; ordinate=average latency in ms.; abscissa=speed in ms. per degree.

FIG. 9. Relationship between speed and action current latency in horizontal counter-clockwise movement of right forearm on disc-apparatus. Leading activity from biceps. Speed calculated between 0° and 20° . $N=43$; ordinate=average latency in ms.; abscissa=speed in ms. per degree.

the elbow rested and the edge of the metal strip which the rising metal arc touched. The arm was strapped to the horizontal board $\frac{1}{2}$ in. over the elbow-crease, permitting an easy movement of the arm at the elbow. In this way the speed and degree of elevation were observed. The results of these experiments are shown in Figs. 10 and 12.

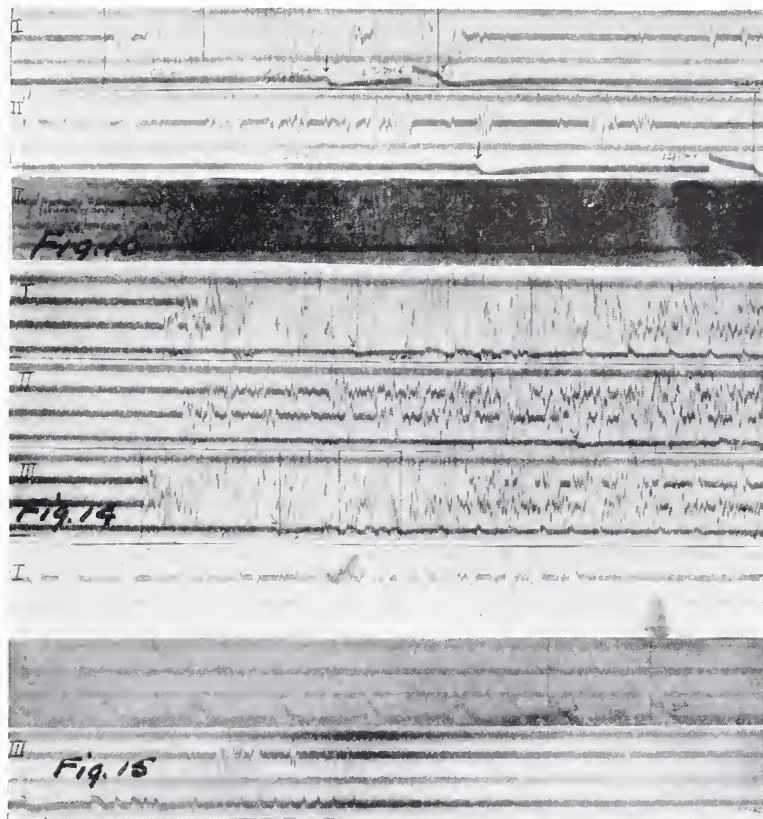


FIG. 10. I. Action current latency for biceps and triceps in fast movement of forearm upwards against gravity (not strapped to radius board). Lines here same as in Fig. 4. I. Arrow at break, beginning of overt movement. Speed of elevation of forearm from 0° to 5° , 42 ms.

II. Slow movement of unstrapped arm upwards. Longer latency than in I.

III. Tension discharges in long head (second line) and short head (third line) of biceps at fast speed due to over-anticipation of signal and lack of relaxation. Beginning of mass action in latent period is clear here and about the same as in other fast movements, but it was considered safe to reject such records for latency studies.

FIG. 14. I. Temporal lead of long head of biceps over short head by 11 ms. when arm was moved from horizontal upwards on arm-arc. Electrodes in stimulable motor points of both. Second and third lines show short and long heads of biceps respectively. Time-line at top, signal at bottom.

II. Temporal lead of proximal (third line) over distal end (second line) of long head of biceps by 13 ms. in upward movement of arm. (Stimulable motor point was in proximal end of long head of biceps, not in the distal).

III. Simultaneous discharges in upward movement of the arm when both pairs of electrodes were .8 cm. apart in long head of biceps. Second and third lines show lateral and medial sides of long head.

FIG. 15. 1. Action current discharges from biceps and triceps in passive movement of forearm from horizontal upwards on arm-arc. Fastest speed recorded here was 22 ms. in 5°, i.e., over 4 ms. per degree. Millisecond time-line at top; biceps, triceps, and signal on next three lines.

II. Almost complete absence of action discharges from biceps and triceps in fourth passive movement of forearm at fast speed after unrecorded habituation trials. Presumably general adjustment to the situation and relaxation caused quieting effect on reflex discharges.

III. Passive movement following 2 sec. pause after habituation trials. Note the fast rate and that discharges are fewer than in I.

Except for *de Jongh* (15) and *Einthoven* (4), most physiologists agree that there is an interval between the beginning of the electrical response and the beginning of the mechanical response. *Fulton* states, "no one has been able to show that the two actually begin with absolute simultaneity" (5). This interval or latency varies with the nature of the muscle activated. The true latency of a frog's gastrocnemius is 1.5 to 2 ms. at 20° C., and the total latency is about eight ms., including the period of rigidity. As the latency of an intact human muscle can be measured only with reference to the output of work in moving its own mass or a limb, it necessarily will differ from the latency of small animal preparations. The latency may be changed further by the speed with which the muscle is made to work.

A study of Figs. 5, 8, and 9 and of the correlations in Table V will emphasize the definite relationships between speed and latency. The reason for this relationship lies in the integrative action of the central nervous system and peripheral muscular structures.

The assemblage of motor neurons (anterior horn cells), each innervating 120 or more muscle fibers, and each constituting with the latter a motor unit, plays its rôle in voluntary muscle work in the manner required in any given circumstance. How many of them will be activated at a particular time depends as much upon cortical control as upon the patterns of discharge along pathways made useful and familiar in a given situation in phylogenetic and ontogenetic neuromuscular development. When a mental set for quick action of a particular body part is translated into proper physiological processes, a large number of motor units come into action and work in phase with each other, giving rise to a large

electric potential and enough energy to get the body part started from its position of rest. On the other hand, when we intend to move the same part in a slow way, the fewer muscle fibers involved produce a smaller amount of electric potential and longer time is needed to build up cooperative activity before the body part can be moved. In other words, the faster the speed the greater the synchronization of muscle fibers and the shorter the latency; the slower the speed the less the synchronization and the longer the latency. In slow speed, motor units working against mechanical weight of the limb are not so completely out of phase as to be ineffective; yet they are enough out of phase before work output to make the period of electrical activity long. That is, the motor units discharge severally and hence long enough before a synergy takes place for the muscle to do the work.

How a visual and kinæsthetic image of a particular speed of movement is transmuted into actual speed of muscle-work through cortical and subcortical reflex and voluntary behavior patterns, within normal variations, and produces its respective latencies, is an instance of psychological and physiological cooperation that can be studied only in an intact organism.

In spite of a definite relationship between speed and latency, the shapes of the curves in Figs. 5, 8, and 9 have not been the same under different conditions of movement. When the arm-arc was used, the average latencies gave a fair approximation to a logarithmic curve, whereas in case of the disc-apparatus and movement of the unstrapped arm the average latencies gave an approximation to a linear relationship. This presumably was due to the presence of only a few latencies at the 'tail-end' of the slow speed. If we had had a larger number of them at the end the true relationship probably would have been more evident.

The latencies at the various speeds appear different under the four experimental conditions. But they are not really so. With the arm-arc, the weight of the radius-board and its attachments and the friction involved called for a synchronous action of a larger number of muscle fibers than was required with the disc-apparatus, where friction and weight were considerably less, or in movement of the unstrapped arm, where friction of apparatus

was entirely absent. Consequently, in the latent period of the latter the amplitude of action currents was very much less than in the former. Also, the form was different. But the important difference was that the synchronization factor due to weight, *etc.*, in the case of the arm-arc, reduced the latencies as compared with those in other situations. For instance, if we examine Figs. 5, 8, and 9 and Tables I, II, III, and IV, it will be noticed that at a speed of movement near or more than 20 ms. per degree, the average latency which the arm-arc gave was the lowest (92.2 ms. per degree) and the available latency on the disc-apparatus was 226 ms. (counter-clockwise), 194 ms. (clockwise), and 174 ms. for the unstrapped arm arrangement, where there was almost no friction, only weight. Although the average latency at a speed of about 20 ms. or over per degree on the disc-apparatus and in the case of the unstrapped arm arrangement, was not so trustworthy, based as it was on so few cases, the evidence is clear that it was much higher than that given by the arm-arc at about the same speed. Hence synchronization of muscle fibers is dependent upon two conditions: speed of movement and work to be done.

There have been seven clear records of a lack of any action currents in the latent period at the slowest speed, six in the clockwise movement and one in the counter-clockwise movement at 16 to 25 ms. per degree. Further, in certain cases there has been noticed a distinct drop in latencies at the slowest speed. Both presumably are caused by the same phenomenon. It has been maintained that at slow stimulations the inactive muscle fibers have a tendency to shunt the potential of the active fibers and no discharge may be recorded. This variable could interfere with either a logarithmic curve or straight line relationship, as far as the 'tail-end' is concerned.

A comparison of the correlations in Table V and Fig. 11, presenting the relationship between speed and latency for all *Ss* shows (1) there are marked individual differences in this relationship, and (2) while individual correlation is quite high in six out of 12 cases the correlation including all but two *Ss* is .62. The reason for the lower correlation is that one *S*, while

TABLE I. *Latencies at different speeds of movement from horizontal upwards. Arm-arc apparatus*

Speed in .001 sec. between 0°-1°	No. of records	Av.	Range	SD
20-59	102	92.2	48-156	21.8
60-99	104	113.4	47-278	43.1
100-139	52	158.6	56-300	58.7
140-179	35	182.1	69-337	73.1
180-219	11	194.0	69-315	69.1
220-259	7	195.7	131-299	
260-299	2	228.0	215-241	
300-339	2	197.0	109-285	
340-379	3	173.0	126-241	
	318	128		

TABLE II. *Latencies at different speeds of clockwise horizontal movement. Disc-apparatus*

Speed in .001 sec. between 1°-10°	Speed per degree	No. of records	Av.	Range	SD
10-59	1-5.9	3	110.0	106-120	7.1
60-109	6-10.9	19	152.1	94-264	56.4
110-159	11-15.9	9	261.0	48-420	100.6
160-209 *	16-20.9	2	194.2	465-506	100.6
210-259 *	21-25.9				
		33	198.2		

* Six zero latencies in both are not figured in the average.

TABLE III. *Latencies at different speeds of counter-clockwise horizontal movement. Disc-apparatus*

Speed in .001 sec. between 0°-20°	Speed per degree	No. of records	Av.	Range	SD
60-109	3-5.4	10	155.1	94-204	33.5
110-159	5.5-7.9	15	186.4	111-297	60.7
160-209	8-10.4	6	205.1	110-320	72.9
210-259	10.5-12.9	8	160.0	37-294	93.5
260-309	13-15.4	2	272.0	249-295	
310-359	15.5-17.9	1	122.0	122	
360-409	18-20.4 *	1	226	226	
		43	180.2		

* One zero latency is not figured in the average.

TABLE IV. *Latencies at different speeds of movement from horizontal upwards. Arm unstrapped*

Speed in .001 sec. between 0°-5°	Speed per degree	No. of records	Av.	Range
30-69	6-13.9	6	88.0	75-103
70-109	14-21.9	3	174.6	121-177
110-149	22-29.9	2	192.5	173-212
150-189	30-37.9	1	318	
		12	146.2	

consistently maintaining a definite straight-line relationship so far as his own records were concerned, gave the longest latency at a speed much slower, or faster, as the case may be, than that given by another *S*. Hence the combined records reduced the correlation. Records taken more than one month apart from one *S* (BKB) showed practically the same level of correlation each time.

Reciprocal innervation of antagonistic muscles. Golla and Hettwer (7), using human *S*s and the electromyographic tech-

TABLE V. *Correlation between speed and action current latency in movement from horizontal upwards. Arm-arc*

Subject	No. records	Correlation		P.E.
		<i>r</i>	<i>rho</i>	
RW	41	.87		.02
BKB	46	.88		.02
JL	39	.57		.07
VR	21		.92	.02
GE	15		.63	.08
AM	19		.58	.09
NHK	24		.73	.06
DRM	24		.80	.05
AHH	15		.60	.09
SPB	18		.60	.09
BKB	17		.87	.03
BKB	23		.80	.03
8 subjects	264	.62		.02

nique, have shown the cooperation, time-relations and the magnitude of response of several pairs of antagonistic muscles and the effect of resistance on that response. Tinley and Pike (23), employing a mechanical myographic set-up for clinical *S*s, and the technique of stimulation of the cerebrum and cerebellum of narcotized animals, came to the conclusion that "muscular co-ordination depends primarily on the synchronous co-contractive relation in the antagonistic muscle groups". They have felt compelled to disagree with what Fulton (5) calls the classical view of reciprocal innervation: that when the agonist contracts the antagonist relaxes (*Sherrington*, 20). The possibility of simultaneous contraction of antagonistic muscles is, however, indicated by *Sherrington* (21, 22). He says that "double reciprocal innervation", i.e., the contraction to a degree of both antagonist and agonist, "represents conditions nearer to the occurrences of daily

life" than simple reflex contraction of an agonist upon relaxation of its antagonist. *Pollock* (18) found reciprocal innervation when contralateral nociceptive stimuli were used on animal preparations, and also in phasic reflexes inhibiting tonic ones. Although he observed simultaneous contraction in the antagonistic muscles in non-tonic reflexes from the neck, accompanying tonic ones when

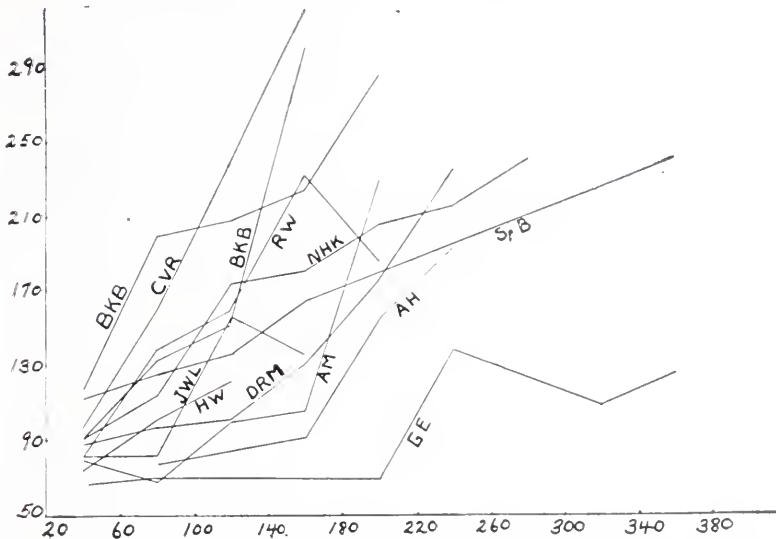


FIG. 11. Individual differences in the relationship between action current latency and speed of movement for right forearm from horizontal upwards. Speed in ms. between 0° and 1° . Arm-arc apparatus. Initials represent S's. Ordinate=average latency in ms.; abscissa=speed in ms. per degree.

strong contralateral nociceptive stimuli were employed, he concludes that "these observations can not be used to determine the behavior of antagonistic muscles in voluntary movements". Recently *Wilson* (29), using the leverage system and kymographic recordings, found in finger movement under various conditions that the agonist and antagonist contract simultaneously or in succession at different rates and amounts, giving overt movements as a resultant. Hence the question concerning reciprocal innervation in intact antagonistic muscle groups is not settled.

The purpose of this part of the research is to determine the temporal and synergic factors in the so-called reciprocal innerva-

tion of biceps and triceps and the extent of co-contraction in voluntary activity with reference to speed. The element of speed has not been measured in the studies just mentioned but its importance will be clear presently.

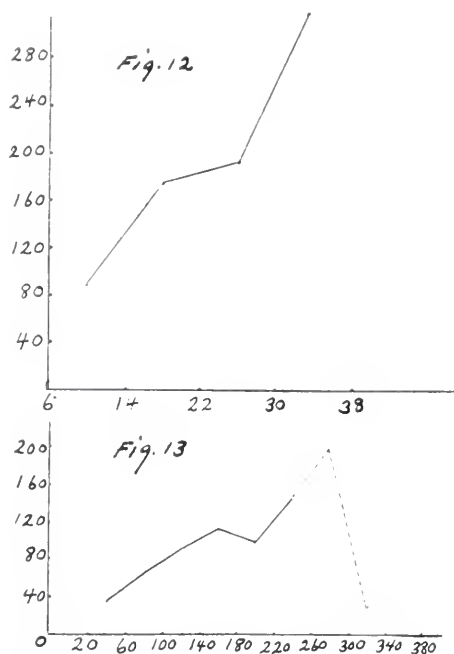


FIG. 12. Relationship between speed and action current latency for biceps in movement of right forearm, unstrapped to radius-board, from horizontal upwards. Speed calculated between 0° and 5° . $N=12$; ordinate=average latency in ms.; abscissa=speed in ms. per degree.

FIG. 13. Relationship between speed and amount of lag in triceps latency in comparison with biceps latency in movement of right forearm from horizontal upwards. Arm-arc. $N=126$; ordinate=average triceps lag (in ms.) in the latent period; abscissa=speed in ms. per degree. Dotted portion of curve based on small number of cases.

Both the arm-arc and the disc-apparatus were used and altogether 326 records were analyzed. The electrodes were in the motor point of the long heads of the right biceps and triceps. Thus was avoided the criticism concerning the use of pseudo-antagonists in such a study. Records showing a poor triceps line, because of bad light or too much fatty tissue in the S, had

to be rejected. And where rhythmical tension discharges were present (Fig. 7-1), only the clear-cut indications of action currents occurring in addition to them in the antagonists were counted. A distinction also could be made between barely notice-

TABLE VI. Amount in ms. by which triceps lags behind biceps in latent period, in movement of right forearm from horizontal upwards at different speeds between zero and one degree. Arm-arc

		Subject							Total
		SPB	CVR	HW	AH	NK	BKB	GE	
Fast speed 20-59 ms. per degree	N	3	5	2		2	18	5	35
	Av.	68.3	17.4	22		35	36.2	35.6	35.3
	SD	15.7	3.3			6	17.8	17.08	19.5
Med. speed 69-99 ms. per degree	N	5		2	7	8	7	3	32
	Av.	83.2		42	42.4	66.5	94.7	58.0	67.6
	SD	21.5			20.6	17.6	37.6		31.5
Slow speed 100 ms. and over per degree	100- 139	N	4	1	4	4	6		19
		Av.	79.2	28	69.7	130	111		95.2
		SD	38.5		22.7	41.9	42.7		46
	140- 179	N	5	2*	1	3	1*	1	13
		Av.	128.4	117.5	87.0	154.6	15	25	112.9
		SD	31			62.2			56.1
	180- 219	N			2	1	1*	1	5
		Av.			104	184	49	41	96.4
		SD							51.2
	220- 259	N				1		1*	2
		Av.				250	0*	40	145
		SD							
	260- 299	N				1			1
		Av.				200			200
		SD							
	300- 339	N						1	1
		Av.						47	47
		SD							
	340- 379	N						1	1
		Av.						94	94
		SD							

* Absence of triceps latency in one unrecorded case.

able discharges quite distant from the electrodes and tube disturbances in the line wherever they were unavoidably present. Some of these discharges were included under the term s.v. (small volleys). For a rough classification, without any intention of exact measurement, other discharges were named large volleys and mass action (see Tables VIII and IX).

We found (Figs. 4 and 10) that the triceps cooperates especially when the biceps is active against gravity: the former does not relax, contrary to what is said usually in psychological literature about the subject of reciprocal innervation. But the triceps activity is tardier than the biceps activity (Fig. 13). Table VI shows that the triceps lags behind the biceps in the latent period by about 35 ms. in fast speed of 20 to 59 ms. per degree, 67 ms. in medium speed of 60 to 99 ms. per degree, and 95 to 200 ms. in slow speed of 100 to 299 ms. per degree.

From a qualitative analysis it is apparent that the full co-operation of the triceps, involving a greater number of response units in fast movement from horizontal upwards against gravity, usually is initiated between 10° and 20°, sometimes earlier (see Fig. 4-1). In slow speed this cooperation is either postponed until 30° to 45° and continued, or may lessen to the extent of small volleys (barely noticeable volleys). There are exceptions and individual differences.

The scatter or variability of the temporal lag of the triceps is tremendous, as Table VI shows. Data on voluntary movements from up downwards (not tabulated), in which the triceps takes the lead, show that the biceps is not passive. It cooperates either in the latent period, or all the way down, or both, with marked individual differences as to its initiation of activity.

The movement of the unstrapped arm upwards and downwards, where there is no mechanical friction and only the weight of the arm, shows the same cooperation although a smaller number of motor units is involved.

The clockwise and counter-clockwise movement on the disc-apparatus (Tables VIII and IX) shows that the synergic action of the antagonist appears between 15 and 100 per cent of the time within a certain speed range: 6 to 21 ms. per degree, in clockwise movement, and three to 13 ms. per degree in counter-clockwise movement. At a slower speed, *i.e.*, slower than 21 ms. per degree, the biceps is observed to be passive when the triceps is active in clockwise movement, and at slower than 13 ms. per degree the triceps is passive when the biceps is active in counter-clockwise movement. So the fact emerges that the clockwise movement

needs the cooperation of the antagonist and the agonist more than the counter-clockwise movement, at a speed slower than 13 ms. per degree.

TABLE VII. *Amount in ms. by which triceps lags behind biceps in latent period in movement of forearm from horizontal upwards, irrespective of speeds*

Subject	N	Av.	Range
SPB	17	92.94	0-166
CVR	7	46.00	0-124
HW	5	26.00	19-62
AH	14	62.20	20-107
NHK	20	111.00	29-250
BKB	33	62.00	0-187
GE	13	46.07	0-97
	109	71.50	

TABLE VIII. *Characteristics of biceps discharge according to speed when triceps is chiefly active in clock-wise movement. Disc-apparatus*

S.V.=small volleys, one or two motor units

L.V.=large volleys, several motor units

M.A.=mass action, many motor units

Speed, ms. per degree	Av. amount of biceps lag in ms. in latent period	Characteristics of biceps discharge between 0°-20° and after, where it was present	Per cent of cases showing biceps latency	Per cent of cases showing biceps discharge between 0°- 20° and after
6-10.9	62	S.V., L.V., M.A.	70	100
11-15.9	6	S.V.	38	47
16-20.9		S.V.	0	15
21-25.9		0	0	0

TABLE IX. *Characteristics of triceps discharge according to speed when biceps is chiefly active in counter-clockwise movement. Disc-apparatus*

Speed, ms. per degree	Av. amount of triceps lag in ms. in latent period	Characteristics of triceps discharge between 0°- 45° and after, where it was present	Per cent of cases showing triceps latency	Per cent of cases showing triceps discharge between 0°- 45° and after
3-5.4	15.5	S.V., M.A.	50	100
5.5-7.9	49	S.V., M.A.	30	100
8-10.4		S.V., L.V.	0	100
10.5-12.9		S.V., M.A.	0	100
13-15.4			doubtful	doubtful
15.5-17.9			"	"
18-20.4			"	"

In the latent period there is noticed the usual lag in the biceps (Fig. 7-1) and triceps in clockwise and counter-clockwise movement, at a speed between 6 and 16 ms. per degree and three to eight ms. per degree respectively (Tables VIII and IX). Below those speeds no cooperation between the antagonistic muscle groups is noticed in the latent period. However, the triceps is more cooperative than the biceps in the latent period as indicated by less lag, and in the post-latent period at speeds up to 13ms. per degree, after which it gives no determinable co-operation.

Although there always has been a lag, the synergic action of the triceps is evident in the latent period and later at a much slower speed on the arm-arc than on the disc-apparatus (counter-clockwise). Rather it has cooperated in the former case at a speed of 97 per cent less than that on the disc-apparatus (Tables VI and VIII). The reason for this is clear. Gravity, weight, and friction (in the arm-arc) have made it imperative that the biceps "summon the aid" of the triceps, which is much less needed when all these factors are present only to a limited degree (in counter-clockwise movement on the disc-apparatus). Also, the size of action currents when the disc-apparatus is used is less, on the whole, than in the case of the arm-arc which brings into action a larger number of motor units.

From all these considerations it is clear that in movement of the forearm in an intact organism there is no absolute reciprocal innervation, nor absolute co-contraction or simultaneous innervation. Rather, there is *cooperative innervation* with a temporal lag and differential intensity on the part of the non-leading member of the antagonistic muscle groups, depending upon the speed at which the postural changes are made in response to environmental demands.

Disparate innervation of the two heads of the biceps brachii. Although anatomically the biceps brachii muscle has been known to have two heads, they have been taken to act more or less as a unit in contraction. In action current work electrodes are usually placed transversely across the belly of the entire muscle or inserted

through the skin of the region known to contain the motor point, or the functional center of the whole muscle.

The purpose of this section is to investigate the temporal order of innervation of the functional centers of the two heads of the muscle and the relationship between the functional centers and the nearby points of the heads at different speeds of movement. The arm-arc was used. Electrodes were placed as indicated in Table X, each pair in a distal-proximal relationship in the biceps. A total of 191 records were taken from four Ss.

TABLE X. *Location and distance in cm. of two pairs of electrodes in biceps; A=electrode pair in the motor point of long head; B=electrode pair in the motor point of short head*

Electrodes	Subjects				
	JL	BKB	BKB	RW	CVR
	Distance in cm.				
A	1.6	1.6	1.9	1.2	0.8
B	1.6	2.5	2.1	1.0	0.9
A ₁	1.3		1.8		
A ₂	1.2				
A ₃			1.6		
A ₄				1.4	
Closest points of A and A ₁	2.2		3.1		
Closest points of A and A ₂	1.6				
Mid-points of A and B	2.3	3.7	4.0	2.6	3.1
Mid-points of A and A ₃			0.7		

AB=one pair of electrodes in stimuable motor point of long head and another pair in stimuable motor point of short head of biceps. A₁B=one pair distal to motor point of long head and another in motor point of short head. A₂B=one pair proximal to motor point of long head and another in motor point of short head. AA₁=one pair in motor point of long head and another pair distal to motor point of same head. AA₂=one pair in motor point of long head (lateral side) and another pair slightly medial to motor point of same head at same level. A₃B=one of a pair proximal to motor point of long head, the other retained in the motor point, and the second pair in motor point of short head.

From Table XI (BKB, AA₁) it may be ascertained that the functional or physiological motor point of the long head of the biceps always has a temporal lead over a non-motor point of the same head in muscle-work against gravity (Table X and Fig. 14-II).

In general there is a temporal lead of the motor point of one head over a non-motor point of the other head (Table XI, JL-A₂B). However, in JL (A₁B) the short head lagged behind the long head more often than not, although the electrodes

were supposed to be in the motor point of the former and distal to the motor point of the latter. The probable reason for this is the slight difference, as pointed out by *Travis and Patterson (26)* in quadriceps femoris, between the physiological motor point and the stimuable motor point.

TABLE XI. *Frequency of lead in the two heads of the biceps with different positions of electrodes**

Electrode location		JL	BKB		RW		CVR
		ai**	ai	as**	ai	as	ai
AB	No. of records	19	14	12	29	19	21
	Long head lead	43%	100%	58%	83%	100%	53%
	Short head lead	36%		25%	10%	100%	33%
	Simultaneous	21%		17%	7%		14%
A ₁ B	No. of records	15					
	Long head lead	47%					
	Short head lead	26½%					
	Simultaneous	26½%					
A ₁ B	No. of records	15					
	Long head lead						
	Short head lead	80%					
	Simultaneous	20%					
AA ₂	No. of records		12				
	Long head motor point lead		100%				
	Long head distal lead						
	Simultaneous						
AA ₂	No. of records		11				
	Lateral side of long head lead						
	Medial side of long head lead						
	Simultaneous		9%				
A ₁ B	No. of records					13	
	Long head lead						
	Short head lead					85%	
	Simultaneous					15%	

* See Table X for exact electrode distance and significance of AB, A₁B, etc.

** ai=arm flat on the radius-board.

as=arm sidewise on the radius-board

Ninety-one per cent simultaneous discharges at electrode positions AA₂ prove that both pairs were at the same motor unit or within the same functional zone of two adjacent motor units (Fig. 14-III and Tables X and XI).

Except for RW and for a few simultaneous records the long head led the short head in the greater percentage of cases, when the stimuable motor points of both heads were utilized (Table XI, and Fig. 14-I). The reason is either that the functional center of the short head was not found because of the aforesaid differ-

ence between stimulable and physiological motor points, or that there was an inherent physiological bias in the long head in arm movement against gravity.

With electrodes in motor points of both heads, significant differences were found in the lead from individual to individual, *viz.*, the long head lead ranged from +3 to 100 per cent of the cases and short head lead from 10 to 36 per cent, and in one individual, 100 per cent of cases (Table XI, AB).

The position of the arm (flat or sidewise on the radius-board) made no difference in the lead with RW, though it did with BKB, but this lead was not consistent. It is quite probable that the difference was due to chance factors rather than to anything related to position of the arm. If it were caused by tension discharges it would have been detected in the records.

From Table XII it will be evident that the scatter or variability around the mean amount of lead of either the long head or the short head is quite large, and that slow speed increases the lead considerably more than fast speed. The latter fact is attributable to asynchronous volleys of the motor units in slow speed, earlier referred to, and the former to the temporal non-specificity of their discharge in connection with the successive movements of a large muscle group.

Passive movement discharges. Wachholder (27) and Wachholder and Altenberger (28), recorded action currents from intact human muscles in passive movement. The sources of these action currents have been a puzzle since they apparently are not produced by any conscious voluntary effort on the part of the individual concerned. Wachholder states that one of the conditions which eliminated them in his experiments was S's attempt to relax psychically as completely as possible, other conditions being sufficiently slow movements, small angular movements, and exclusion of gravity.

McKinley and Berkwitz (17) reported before the American Neurological Association what they called 'tonus tracings' from human muscles, biceps and triceps. They connected those muscles with the amplifier and oscillograph and turned the hand, resting on a rotating and almost frictionless support, horizontally inward

TABLE N11 Amount of lead in ms. of the long head or short head of the right biceps brachii at different speeds

		JL		BKB 12-6-34		BKB 12-11-34				RW	CVR	Total
						A	B	D				
Fast-medium speed 20-99 ms. per degree	Long head	N	12		13	11	7	9			6	58
		Av.	6.66		6.2	18	7.7	11.3			7.6	9.68
	Short head	SD	1.6		3.7	7.5	7.3	2.7			6.8	7.45
		N	8	8	3		2			26	5	52
Slow-speed 100 ms. and over per degree	Long head	Av.	16	7.27	5.3		2.5		16		6.4	12.6
		SD	8.12	5.4	1.18		1.22		12.7		3.7	10.9
	Short head	N			11	3		2			5	21
		Av.			43.8	50.3		9.5			47.4	42.3
Coeff. var. as between fast and slow speed	Long head	SD			31.2	22.6		3.3			11.6	27.9
		N	4				1		14		2	21
	Short head	Av.	38.2				16		33.7		22	32.6
		SD	9						22.3		5	19.5
Coeff. var. as between fast and slow speed					.83	.92		.68			3.65	1.16
Coeff. var. as between fast and slow speed			3.15						.49			1.44

or outward with the help of various weights suspended over pulleys. Their results were not uniform. With some *Ss* there were discharges in biceps, with others in triceps, and with still others in both, under identical conditions. They thought that "the rôle of voluntary or higher reflex mechanisms in producing fluctuations cannot be discarded". They also mention the factor of lack of relaxation. But they added that "relaxation with the arm at rest was readily attained in practically every experiment, but relaxation during the movement in the arm was evidently a matter not so much of volition as of the general physiological make-up" and that further study should be done on it.

The purpose of this part of the research is to investigate the bearing of speed, short rest, habituation, and pause on the discharges in passive movement. These four conditions were introduced as follows:

1. *S* was asked to close his eyes, relax, and consciously eliminate all voluntary effort when his arm, strapped to the radius-board, was, without any signal to him, moved by *E* up and down on the arm-arc, or clockwise or counter-clockwise on the disc-apparatus at various speeds with about 1 min. interval between each pair of movements.

2. A 3 min. relaxation period was interposed and a passive movement record immediately following it was taken.

3. *E* moved the radius-board and the strapped arm up and down on the arm-arc seven times without any appreciable interval between movements, to create a condition of habituation to the situation, and the eighth passive movement immediately following the seventh was recorded, and sometimes three other successive movements were also photographed.

4. The condition was the same as for (3) except that between the seventh habituation trial and the passive movement for the eighth time a pause of 1 to 2 sec. was introduced and then the eighth movement was recorded.

The order or plan of this experiment was unknown to *S*. The laboratory was quiet as possible.

In order to measure, wherever possible, the amount and extent of discharges in passive movement, for the sake of comparison under the four conditions, the following standard was set up and observed within small limits of error. Action currents with a duration of 9 to 12 ms., and an amplitude of 1.5 cm. or over from the base-line of the record were described as large mass action. Action currents lasting 4 to 8 ms. and less than 1.5 cm. high were termed medium mass-action. Small volleys were 2 to

3 ms. long and less than 1.5 cm. in amplitude. When there was a continuous mass action it was divided into several mass action blocks, each 12 ms. long.

From an analysis of 226 records of passive movement at various speeds (3 to 313 ms. per degree), during the initial and later stages of the movement and in different directions—antigravity (96 records), gravity (60 records), clockwise (31 records), counter-clockwise (25 records), and in unstrapped arm-arrangement (14 records)—the following facts emerged.

There were no action currents before the first break in passive movement for either head of the biceps or for the triceps at any speed in any direction except for a few adventitious discharges in the clockwise and counter-clockwise movements. These discharges occurred in 6 per cent of the cases in the latent period for biceps and triceps in clockwise movement, in 4 per cent of cases in the latent period for triceps in counter-clockwise movement.

Action current discharges in the muscles under consideration occurred only twice in passive movement between 0° and 5° against gravity, and only four times between 75° and 70° with gravity. There were biceps discharges in 48 and triceps discharges in 44 per cent of cases in counter-clockwise movement between 0° and 20° ; there were biceps discharges in nine and triceps discharges in 22 per cent of cases in clockwise movement between 0° and 10° on the disc-apparatus.

In general there has been some form of action current discharges, single volleys, medium mass action or large mass action, anywhere between five and 75° in the biceps or in the triceps or both, when the arm was passively raised from 0° against gravity or moved downwards to 0° from 70° with gravity on the arm-arc (Fig. 15-1). This was true also for passive movement of the unstrapped hand beyond 5° and for the clockwise and counter-clockwise movements beyond 10° and 20° respectively, with a few exceptions in the last instance. The location of their appearance was not the same from person to person or from trial to trial in the same person, although in many records was found a critical angle between 15° and 30° from

horizontal, at which action currents invariably appeared. This becomes significant when we recall that in many instances the triceps cooperated vigorously at about that region in voluntary movement.

At fast speeds there was a greater possibility for the appearance of these discharges than at slow speeds, yet the speed factor did not seem absolutely important in every case. For in fastest speeds, *c.g.*, 4 to 6 ms. per degree (Fig. 15-II), there were negligible or no passive discharges on some records from BKB, AH, GE, and NK, whereas in slow speed (141 ms. initially and 68 ms. at a later stage, per degree) large action currents were found in GE. There must have been a factor other than speed to account for these discrepancies. The form of these discharges varied from individual to individual. Some had a greater degree of large mass action while others had a larger number of single volleys or more medium mass action within the same speed range.

Compared with each *S*'s own first normal record of upward or downward passive movement, the first record taken after a 3 min. relaxation showed a distinct increase of action currents in 64 and decrease in 36 per cent of the cases. But the first passive movement after habituation trials indicated an increase of action currents in only 28 and decrease in 72 per cent of the cases, the second record after habituation trials an increase in 36 and decrease in 64 per cent of the cases, the third record after habituation trials an increase in 44 and decrease in 56 per cent of the cases, and the fourth record after habituation trials an increase in 20 and decrease in 80 per cent of the cases (Fig. 15-II).

The evidence seems to point to the conclusion that the decrease of action currents in passive movement was due not necessarily to slow speed (as many were fast-speed records), but to the way *S* reacted to the situation of his arm movement. If he became accustomed to the latter and paid little attention to the passive movement while it was going on, there were no discharges. Apparently the tendency to help or resist the movement was quieted. But 'paying little attention' presupposes not only an ability psychologically to dissociate from the act of movement, but a

physiological state of relaxation which keeps the various reflexes from manifesting themselves. The fact that, in a large number of cases, passive movement after a rest of three minutes increased action currents suggests the possibility of some form of startle calling forth helping or resisting movement, or of a response like the righting reflex.

In several instances a pause of about 2 sec. before the last (eighth) habituation trial at the fast speed distinctly reduced action currents (Fig. 15-III). This may be due either to the fact that (1) *S* was caught unaware and had no opportunity to react to a situation different from the preceding habituation trials or (2) a short pause leads to a period of neuromuscular re-adjustment, quieting the activity of possible sources of response. Probably the latter alternative is true.

Action current discharges in attention. Some of the classical experiments on attention relate to the recording of heart beat, breathing and other physiological manifestations. Tachistoscopic techniques investigated the so-called span of attention or apprehension with its different levels of clearness. However, from the standpoint of systematic psychology, the subject of attention has presented a problem which is far from being settled. Attention might be equated to consciousness, as some have done without much success, or conceived of in terms of energy, or as a state or condition of the appearance of mental phenomena, or as a manifestation of will constituting a 'sense of innervation'; there has been no universal agreement about its real nature. Physiologically, the situation has not been investigated except in sporadic instances. Yet attention is intimately interwoven with our mental and probably with our biological life. Here we shall accept attention in its popular sense—focusing of consciousness. Our purpose is to investigate electromyographically the relation of attention to two types of image, visual and kinæsthetic. Although imaging involves attention, attention to a particular image connotes a mental activity which may suggest more degrees than ordinarily are implied in the term 'imaging'.

We have attempted to obtain action current pictures under

the following conditions: (1) quiet attention to a visual image of the right upper arm—plain visualization; (2) quiet kinæsthetic attention (or quiet attention to the imaged movement of the right upper arm); and (3) strained kinæsthetic attention, or intensive attention to the imaged movement of the right upper arm. The terms 'quiet' and 'strained' were used to convey a psychological differentiation to the minds of the *Ss* and our aim was to find a difference, if any, in electromyographic phenomena. When *S* attended quietly to a mental image of movement his total reaction was supposed to be devoid of movement or psychological excitation; yet a steady focusing upon imaging the movement was to be maintained. In strained attention, an intensive mental set was advised—complete and forceful abandon to the act of focusing on the imaged movement but without deliberate tension in the muscle group involved. It required practice, several minutes a day for several weeks, for *Ss* to secure this differentiation as part of their reaction-pattern to this particular experimentation. To secure a better preparation and orientation, relaxation also was practiced.

Jacobson (12, 13) found in 93 per cent of tests on imaging weight-lifting by the upper arm an average increase of electrical potential to the extent of 32 microvolts, nine microvolts being observed in control cases. The extent was 50 to 83 microvolts with prolonged imaging. An amplifier-string galvanometer system was used. The electrodes were six to eight cm. apart. *Jacobson* measured the amplitude of the action currents in microvolts, but not the frequency with which they occurred, for his photographic arrangement was too slow to record frequency accurately (his time unit being $1/5$ sec.). For two reasons we have recorded the frequency without regard to amplitude or microvoltage. In the first place, although the operation of the all-or-none law theoretically should make the discharges of equal amplitude, an unequal distance from the electrodes of the discharging muscle units from person to person or in the same person at different times makes the amplitudes of the discharges unequal. Not much would be gained by averaging the micro-

voltages, for our aim mainly is to investigate what is happening in a specially localized area with which the needle electrodes are in contact.

In the second place, our amplifying system, though registering the occurrence of low-frequency discharges whose harmonics fall within its limited range, is unreliable as to amplitude measurements of frequencies whose fundamentals fall outside this range. Obviously, the low frequency discharge of the single motor units we found in our investigation is rich in harmonics.

S lay relaxed on the cot with his outstretched arm strapped to the radius-board. This was intended to control his gross overt movement, which immediately would be shown by a break signal at the 0 mark. For a check on fine movements of his biceps, a thin, stiff wire, with one end taped to the biceps and looped three inches from that end around a firmly mounted polished nail which acted as a fulcrum, was extended 21 in. so that movement of the tip gave seven-fold magnification of any fine movement taking place in the muscle. This lever system was used with several *SS*, near the end of the study. The long end of the free lever-arm was constantly watched for any extraneous movement other than the rhythmic ones in breathing, heartbeat, and tremor. The laboratory was as quiet as possible. Instructions like the following were given for three separate occasions after a 2 min. period of relaxation:

"Relax as much as you can. With eyes closed think of the biceps of your right arm. Pay quiet attention to its visual image. As you visualize, keep perfectly relaxed."

"Relax as much as you can. With eyes closed, quickly think of moving up your right arm against a 10 lb. weight. Pay quiet attention to this image of movement against weight but try to be perfectly relaxed."

"Relax as much as you can. But this time with eyes closed think in a *very potent manner* of moving up your right arm against a 10 lb weight. Pay strained attention to this image of movement against weight, but do not try to make any deliberate movement

During the experiment, *E* listened on the earphones to detect discharges in either the biceps or triceps and an assistant turned the camera immediately at the silent signal to photograph the discharges. Many observations also were made without photog-

raphy. Electrodes were eight to 16 mm. apart. Occasionally long records were taken from the Ss.

On no occasion was the arm-lever seen to make any extraneous movement except once when the arm made an overt movement, breaking the signal. This record was rejected. No determinable action current discharge was heard or photographed from the right biceps of three Ss for 3 min. or over during attention to a visual image of it (plain visualization). This is on the basis of six records and many observations, and within the sensitivity of the amplifying system.

Action currents were heard and photographed from the right biceps of four Ss (VB, AM, NK, AH) during quiet attention of three minutes or over to the imaged movement of the arm (quiet kinæsthetic attention). From four other Ss (DM, SPB, BKB, GE) no determinable action currents were noted under the same condition. Out of 25 records, 15 were positive (60 per cent) and 10 negative (40 per cent), an unequal number of records being taken from the Ss.

Strained or intent attention to the imaged movement of the arm (strained kinæsthetic attention) gave action current discharges in six Ss (VB, DM, GE, AH, NK, BKB). No action currents were noticed in AM and SPB, under apparently the same conditions. Out of 41 records, 36 were positive (88 per cent) and five negative (12 per cent).

Action current discharges were observed to consist of three patterns: (1) single motor unit discharges with a frequency of seven to 18 per second, varying with the individual; (2) grouped discharges of double or more motor units with one or more single motor units discharging in between and having a frequency of 10 to 20 per second; and (3) irregular discharges.

VB had the single motor unit pattern in quiet kinæsthetic attention (9 per sec.) and either retained in strained kinaesthetic attention the same pattern with a larger frequency (11 to 13 per sec.) or passed on to the grouped discharge pattern consisting of double motor units (14–20 per sec.) (Fig. 16-III; 18-III).

AM and AH had the grouped discharge pattern of many motor

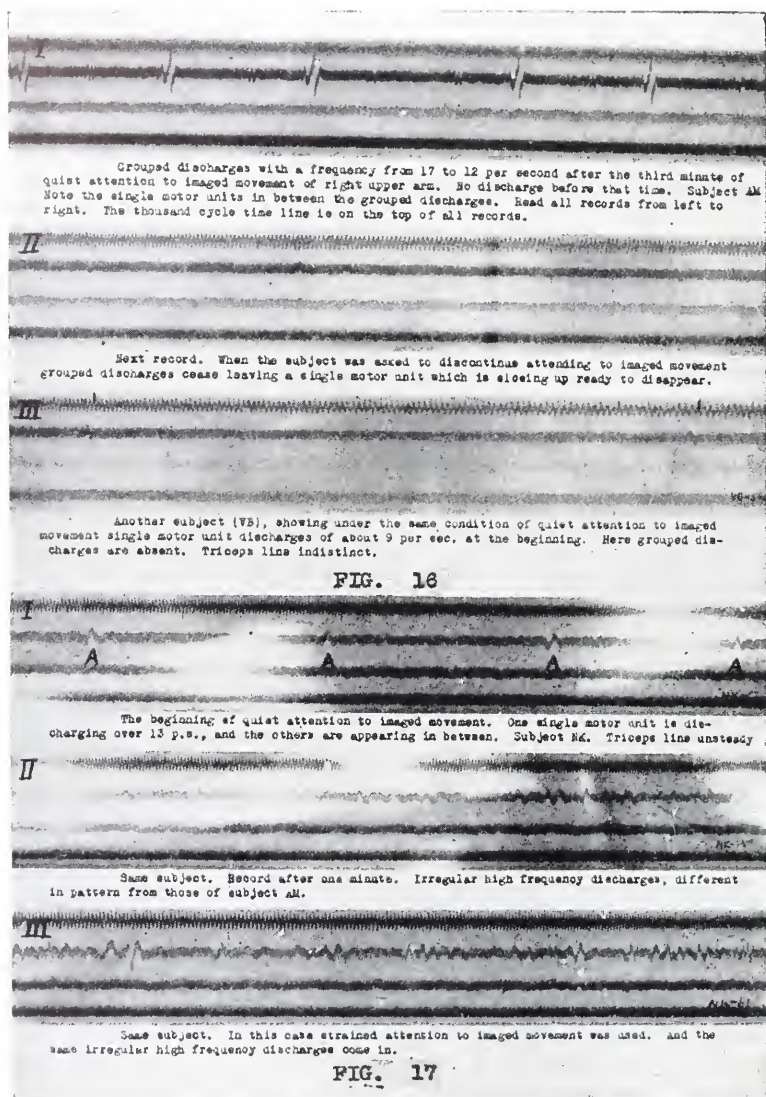


FIG. 16, I, II, III. Grouped and single motor unit discharges in attention to imaged movement.

FIG. 17, I, II, III. Irregular discharges from an S in attention to imaged movement.

units with a frequency of 12 to 17 per sec. in quiet kinæsthetic attention and retained the same pattern with a larger frequency, 14 to 20 per sec. in strained kinæsthetic attention (except AM who showed negative results in the latter, Fig. 18-I). GE also had the same pattern in quiet and strained kinæsthetic attention. Once in the latter instance he showed single motor unit volleys, as DM who, however, had none in quiet kinæsthetic attention. A clear record of strained kinæsthetic attention from AH showed a sudden beginning of grouped discharges preceded by a long absolute quietness on the line.

NK had the single motor unit pattern in quiet kinæsthetic attention with a frequency of about 13 to 14 per sec. at the very beginning. He then developed an irregular pattern of many low amplitude and high frequency discharges and retained it right through strained kinæsthetic attention (Fig. 17-I, II, III).

BKB, who had no discharge in quiet kinæsthetic attention, had only a single motor unit pattern in strained kinæsthetic attention with a frequency of 7 to 10 per sec. That was true also of DM who had, however, a greater frequency, 12 to 18 per sec.

Attention periods were interspersed with short relaxation periods and several records were taken from each *S* to insure these patterns.

It took from 15 sec. to 4 min., more often 3 min., before the motor units discharged after instruction to attend was given. This may be called *attention latency*, in terms of action currents.

Fig. 18-III is a clear picture showing the addition of single motor units as the strained kinæsthetic attention was just starting. These single motor units can be identified by their form.

In every case, with both forms of attention (quiet or strained), a verbal instruction 'stop thinking' or 'stop attending' or 'relax' resulted within about a second in lessening of the speed of single motor unit discharges, and in the case of grouped discharges, in the dropping out of extra units before complete cessation of discharges (Fig. 19-I and I cont'd). Sometimes this dropping out process required a longer time (AH).

In VB and BKB, very slow discharges were found near the cessation of attention; the slowest were from BKB, 210 ms.

apart, i.e., less than five per sec. (Fig. 19-III). We found no action currents from the right biceps when there was strained attention to the imaged movement of the left biceps, left forearm,

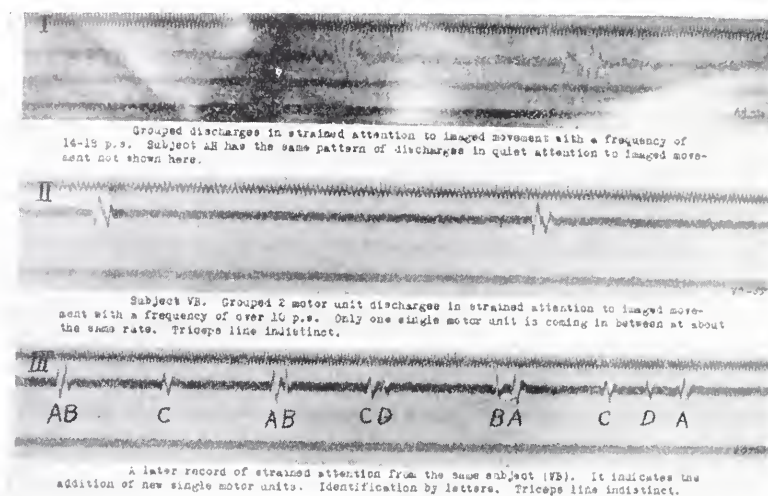


FIG. 18

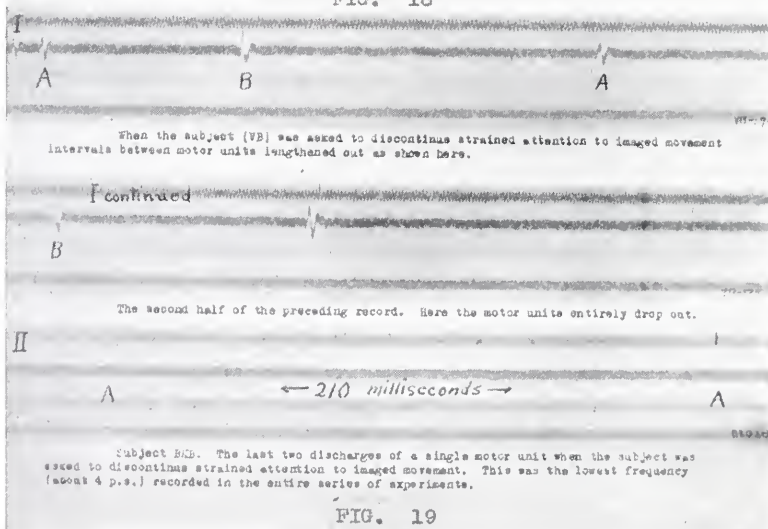


FIG. 19

Fig. 18, I, II, III. Grouped discharges of many motor units and double motor units in attention to imaged movement.

Fig. 19, I, II. Disappearance of discharge of motor units upon discontinuance of attention to imaged movement.

right hand, or actual tension of neck muscles or closing of right hand.

It has not been possible consistently to relate attention and imaging to a particular action current pattern, probably because of the presence of the unknown variable, namely, the degree to which the *S* was or was not differentiating between kinds of attention and imaging in successive experiments. Here an introspective report and correction at any sitting would have been of little use, since the slightest undetectable psychological change might have changed the physiological reaction to above or below its respective effective level.

Although the kind of attention and imaging could not be correlated consistently with action current pattern in the few cases studied, *S* and action current pattern were related, at least to a degree. What is meant is that although each *S* may have started with a different pattern (single motor units or grouped discharge patterns), at a later stage of attention (quiet or strained), he continued or developed his own pattern and adhered to it until asked to stop attending. That is, he developed grouped discharges with double motor units in them (VB) or grouped discharges with many more units (AM, AH, GE) or continued his own single motor unit pattern (BKB). In the rising degree of attention, quiet to strained, there was always a consistency or a consistent change in pattern, and no reversal (except once in GE, which may have been due to the reasons pointed out in the last paragraph).

This experiment does not seek to prove or disprove the motor theory of consciousness. It only calls attention to the fact that specific attention to the imaged movement of a body part causes neuromuscular changes that are similar, in fundamental manifestation, to the changes involved in the actual movement of the same part. It has been pointed out by *Adrian* (2) and others that minimal voluntary movement is dependent upon a certain frequency of nerve impulses (as low as 6 per sec.) causing negative variation in the muscle fibers. Increased movement depends upon greater frequency of nerve impulses (up to 50 per sec. and more) and greater addition of motor units. That is the

situation in our experiment. Although there was no overt movement, there was no questioning the existence of incipient tension during attention; and it produced noticeable neuromuscular changes. Whether or not quiet attention produces detectable tension is not settled. Some *Ss* have not manifested it. Whether that is due to an ability to differentiate from strained attention which is possessed to a greater degree by some than by others, or to a falling back on visualization where no change has been found, or to less disturbance of neuromuscular equilibrium, or to lack of sensitivity of the instruments here used, can not be ascertained. However, the relative results can be studied. Allowing for photographic delays at times to catch the first or middle portion of attention records, the dominant pattern for strained attention, seen time and again, can be laid down for each *S* with fair certainty—single motor unit discharges from BKB and DM, grouped discharges of two motor units from VB, grouped discharges of many units from AH, AM, and probably GE, with single or more motor units intervening, and irregular discharges from NK. Whether this implies a differential neuromuscular functioning at a certain minimal level for different individuals is a matter of speculation at this point or research.

Post-relaxation latency in voluntary movement. The effect of relaxation on tonus was investigated from both a clinical and an experimental angle by *Jacobson* (14). He found that the knee jerk and flexion reflex were decreased through relaxation, and he attributed this decrease to the decrease of tonus. Our aim here was to obtain a measurement of relaxation-tonus in terms of action current latency in movement immediately following relaxation. This represents only a preliminary approach to the study, based on a few *Ss*. The initial training period in relaxation was not as intensive as could have been desired, and limited only to several weeks in all cases except one. Hence the results are tentative. For their daily practice the *Ss* were instructed to lie down as comfortably as they could on a bed or a reclining chair and 'let go' all the body parts, then quietly to attend to each part from head to foot and make it as limp as possible. They were asked then to withdraw their attention from

their body parts, and from sensory or imaginal specificities, *i.e.*, sensation or weight, pressure of the cot against the body, visual, kinæsthetic or memory images, *etc.*, and to slip gradually into the passivity of sleep without actually falling asleep. They were to keep instead a sense of *general awareness*, a quiet minimal attention to nothing in particular but to the field of diffused consciousness. In this respect we differ from *Jacobson*, who does not use the attention factor as such beyond a certain point in the practice, whereas in our method, attention, at least in its quiet, minimal, and non-specific form, is retained throughout. Further, the end product of *Jacobson's* relaxation is usually sleep, whereas our method seeks an end product distinct from sleep. The reason for this difference is that we wanted (1) to measure the effect of relaxation and not of sleep, (2) to control the psychological factor as far as possible. Whether the psychological factor is useful in bringing about better relaxation is out of the province of this study.

The laboratory was practically noiseless. The electrodes were in the biceps and triceps. *S* lay with his arm strapped to the radius-board and followed the regime of relaxation. A minimum period of 12 min. and a maximum period of 30 min. were allowed for an *S*. *E* and his helper either stayed inside the room without making any sound or stepped out and came in noiselessly at the end of the period of relaxation to get everything ready. *S* was given only an audible signal 'ready', at which he moved his arm up on the arm-arc at any time and at any speed he chose (preferably medium or slow), without being over-anxious in any way. Immediately before the ready signal was given the camera was started and kept turning so as to be able to catch the first, most important movement of the arm of *S*. Only a few successes were attained after a great many failures due to short-photographing, slow-photographing, delays, confessed inability of *Ss* to relax because of too many extraneous thoughts, because of the laboratory conditions, or mild excitement directly preceding the movement. Two or three successive records were taken from each *S*.

For the first movement of the forearm after relaxation, the latency was found to be comparatively great. To correctly inter-

pret this latency we noted the speed at which it occurred between 0 and 1 and compared it with the latency at the same or approximately the same speed in normal series of movements. This latency norm was obtained either by averaging several latencies at approximately the speed for which we were seeking a norm, or if that was not possible, by finding the latency ordinate on the known speed from a graph prepared to indicate a general straight line relationship between *S*'s normal speed and latency. The ideal method would have been to use a regression equation but that would not be justifiable unless we had many more records from each *S*. We then obtained a ratio between that normal latency and speed. We also obtained a 'relaxation ratio' between the increased latency after relaxation and the same speed, and compared the two ratios.

TABLE XIII. *Relaxation ratio as compared with normal ratio between speed of movement and latency*

Subject	Normal latency/speed	Relaxation latency/speed	Normal ratio	Relaxation ratio
1	$\frac{250}{136}$	$\frac{600}{136}$	1.83	4.41
2	$\frac{330}{226}$	$\frac{505}{226}$	1.46	2.23
3	$\frac{230}{123}$	$\frac{411}{123}$	1.86	3.34
4	$\frac{150}{275}$	$\frac{305}{275}$	.54	1.10
5	not available	$\frac{234}{84}$		2.78

From Table XIII it is clear that in the few readable records relaxation increased the latency of the first movement two to three times over the normal. There was a case, not recorded, where no difference was found. This probably can be explained on the basis of disturbing conditions and consequent failure to relax. In the three *S*'s from whom we have good records, the second movement after relaxation gave only a slightly increased latency compared with normal at about the same speed, and the third movement was about the same as normal. These decreasing latencies make the long latency of the first movement meaningful;

they are an indication of gradual disappearance of the neuromuscular condition produced by relaxation. To interpret the long latency of the first movement, relaxation causes reduction of the tonicity of muscle fibers. In doing any muscle work against weight and gravity they are much slower and more asynchronous in their action than when normal, prolonging their electrical activity before output in work is possible. Whether any other method of relaxation would have produced the same result or whether this long asynchronous activity of the muscle fibers immediately following relaxation is a prelude to a more organized and possibly more healthful activity in daily work is beyond the scope of this investigation.

IV. Summary and conclusions. This study was set up to investigate the relationships between physiological and psychological processes.

1. The relationship between speed of voluntary movement of the forearm and action current latency for the biceps or its leading head was investigated under various conditions, *i.e.*, against gravity, with gravity, and in horizontal action (clockwise and counter-clockwise). It was found, in general, that the faster is the speed of movement, the shorter is the latency, and up to a certain point, the slower the speed the longer the latency. The correlation was $.62 \pm .02$. The highest individual correlation was $.92 \pm .01$. Greater synchronization of muscle fibers in fast muscle-work and its relative absence in slow muscle-work was offered as an interpretation of this result. The relationship between the mental set to execute various speeds and the physiological phenomena in the form of respective latencies was pointed out.

2. In the so-called reciprocal innervation of antagonistic muscles it was found that when the agonist acted against gravity and friction the antagonist did not relax but co-operated, with a lag of 35 ms. in fast speed (20 to 59 ms. per degree), 67 ms. in medium speed (60 to 99 ms. per degree), and 90 to 200 ms. in slow speed (100 to 299 ms. per degree). There also was a synergic action between the antagonists in horizontal clockwise and counter-clockwise movement, in 15 to 100 per cent of cases

within a certain speed range, with fewer motor units involved than in the case of anti-gravity movement. It was concluded that in the voluntary movement of the forearm of an intact organism there was no absolute reciprocal innervation, or absolute co-contraction or simultaneous innervation. Rather, there is co-operative innervation with a temporal lag and differential intensity on the part of the non-leading member of antagonistic muscle groups, depending upon the speed at which the postural changes are made in response to environmental demands.

3. The two heads of the biceps were not innervated simultaneously in movement against gravity. The physiological motor point of the long head of the biceps was found always to have a temporal lead over a non-motor point of the same head, and in many cases over the motor point of the short lead. The latter finding was thought to be due either to the fact that stimulable and physiological motor points were not the same or that there was an inherent physiological bias in the long head under this condition of movement. Ninety-one per cent of simultaneous discharges came from the long head when the electrodes were supposedly in the same motor unit or within the same functional zone of two adjacent motor units. The increased length of the lead in slow speed and its great variability were attributed respectively to asynchronous action of motor units in slow speed, and to the temporal non-specificity of their discharge in the innervation of a large muscle group.

4. Discharges in passive movement were investigated in relation to speed, rest, habituation, and a short pause, one to two seconds. The discharges came oftener in fast than in slow speed, although such was not always the case, since habituation trials and short pauses (2 sec.) had a quieting effect on them even at the fastest speed. Psychological dissociation from the act of movement, and general relaxation were thought to underlie this quieting effect. Passive movement after a three-minute rest often increased action currents. This possibly was due to startle.

5. There were three patterns of discharges in strained attention to imaged movement: single motor unit discharges with a frequency of 7 to 10 per sec., grouped discharges of double

motor units, 14 to 20 per sec., or of many units, with single motor units intervening, and irregular high frequency discharges. There was a tendency for Ss to adhere to their own patterns, suggesting possibly a differential neuromuscular functioning at a minimal level. In only 60 per cent of cases were there discharges during quiet attention to imaged movement. There were no determinable action currents in plain visualization.

6. Voluntary movement against gravity after 12 to 30 min. of relaxation increased the latency from two to three times over normal. This was explained as an effect of the greater asynchronism of discharge due to the reduction of the tonicity of the muscle fibers.

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AN ACTION CURRENT STUDY OF THE CONDITIONED HAND WITHDRAWAL

by

ARNOLD HENRY HILDEN

1. Introduction. One of the fundamental tools used in the investigation of psychological problems is the conditioned response. Of the conditioned responses available, the conditioned hand withdrawal seems to be as widely used as any. This is due to its relative accessibility and the ease with which it is conditioned. Unfortunately, a great many criticisms have been directed against its validity, and many psychologists have refused to consider it a true conditioned response, since it is too subject to voluntary control. There is need for an investigation which would seek to determine its characteristics, and differentiate it from the voluntary act in the usual reaction-time situation.

The conditioned withdrawal response was the basic procedure used by *Bekterev* (4). Earlier experiments in his laboratory involved shock to the foot. Later, shock was given to the hand instead of the foot (6). "With human subjects the shock usually has been delivered to the end of one or more of the fingers. The heel of the hand rests on a board electrode, and the tip of the finger on another" (4). The usual recording device was that invented by *Watson*. A tambour recording arrangement gives a graphic record of the finger movement. This general procedure has been used by *Hamel*, *Scott*, *Wolfe*, *Shipley*, *Garvey*, *Switzer*, and others. For these details the reader is referred to *Hull's* (4), excellent survey of the field of the conditioned response.

One of the few analytic studies of the conditioned hand withdrawal response was made by *Hamel* (1). Because some *Ss* responded before the conditioned stimulus was given while others showed very long response latencies, he used the mode to express the central tendencies of these latencies. For all *Ss* the mode fell

between 150 and 200 ms. In discrimination reactions (between the sounds of a bell and a hammer stroke), the voluntary response latencies fell within the same range. The reflex latencies to shock were shorter, varying around a mean of 100 ms. *Hamel's* results appear to be the only data reported on the response latencies of the conditioned finger withdrawal. The other studies involving this subject need not be reviewed here.

The present study was formulated as an attempt to investigate the development of the conditioned hand withdrawal, by means of the action current technique. This technique makes it possible, during the development of a conditioned motor response, to record the very slight muscular contractions that precede the overt movement of the hand. It likewise shows the reverse process during experimental extinction. In addition, it possesses the advantage of recording with exactitude the response latencies, in terms of both action currents and overt movement.

The following problems were set up for investigation: (1) the development and extinction of the conditioned response, in terms of magnitude of action currents, action current latencies, overt movement latencies, and the interval between the initiation of the action current and the initiation of the overt response (action current-overt response interval); (2) differentiation between the conditioned and the voluntary response in terms of development and extinction, response latencies, the action current-overt response interval, and subjective report; (3) differences in the responses of the two hands when simultaneously conditioned, as related to the handedness of *S*, these differences to be expressed in terms of action current latencies, overt movement latencies, action current-overt response interval, and the frequency with which the preferred and non-preferred hand led.

II. Apparatus and procedure. *S* was seated in a chair having arm rests wide enough for the arms to rest naturally (Fig. 1). A pad of gauze moistened with saturated salt solution was placed on the inner side of the wrist. Over this, and encircling the wrist, was fastened a band of flexible, tinned-brass braiding, one inch in width. This served as the diffuse shock-electrode. The concentrated shock-electrode was placed near the tip of the

middle finger. It consisted of a round, flat disc of copper, 7 mm. in diameter and 1 mm. thick, fastened to the finger with adhesive tape. Thus *S* could not in any way avoid the shock, whether he withdrew prematurely or not. These electrodes were connected



FIG. 1. *S* in readiness for the experiment.



FIG. 2. Pendulum for controlling the time intervals between light and shock. Operation of the double-circuit key switch (1) closes the light circuit and releases the pendulum, which breaks the light circuit at the upper trip-switch (2) and closes the shock circuit at the lower trip-switch (3).

across a variable condenser, which delivered a single shock of any desired intensity, from sub-threshold strength to more than any *S* could endure. A wide band of cloth encircling the arm of the chair and the arm of *S* at or proximal to the wrist served to prevent the whole arm from moving when stimulated. This was done to make certain that the movement resulting from stimulation was effected by the same muscle groups throughout the series. The procedure was the same for both hands. The cir-

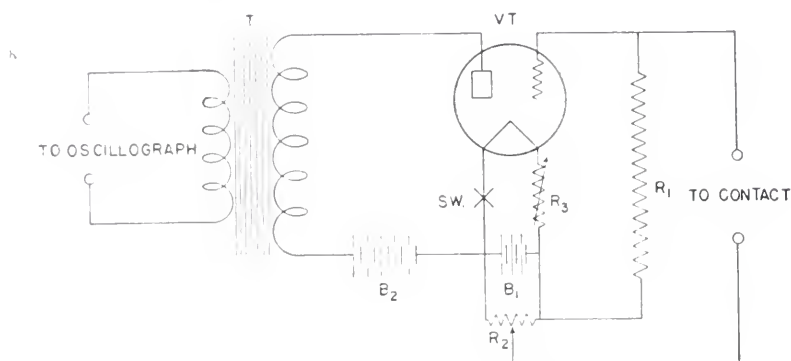


FIG. 3. A wiring diagram of a vacuum tube signal circuit. R_1 =one megohm; R_2 =200 ohm potentiometer for control of signal deflection; R_3 =25 ohm rheostat; B_1 =3-volt A-battery; B_2 =90-volt B-battery; Sw.=s.p.s.t. switch; T=100-to-1 step-down transformer; VT=Type 31 or Type 864 tube (depending on the form of deflection desired, see text).

cuits to the two hands could be separately controlled, as will be described later.

The recording apparatus consisted of two perfectly matched, non-interfering, three-stage resistance-coupled amplifiers, a Westinghouse oscillograph, a General Radio low frequency, type 377-B oscillator, and two signal circuits. The two amplifying-recording units were perfectly matched; equal inputs gave equal outputs. A detailed description of the apparatus is given by *Travis and Dorsey* (8). The apparatus used here differed only with respect to the signal circuits.

The two signal circuits (Fig. 3) had identical hook-ups. Each circuit consisted essentially of a vacuum tube and output transformer so arranged that making or breaking the input circuit

caused a variation in the plate current. This variation was transferred to the oscillograph element by means of the output transformer. The magnitude of the current flowing through the input circuit before the contact was broken was of the order of one microampere.

The secondaries of the two output transformers were connected in series across the oscillograph element. Differentiation of the response from the two hands was effected by dissimilarity

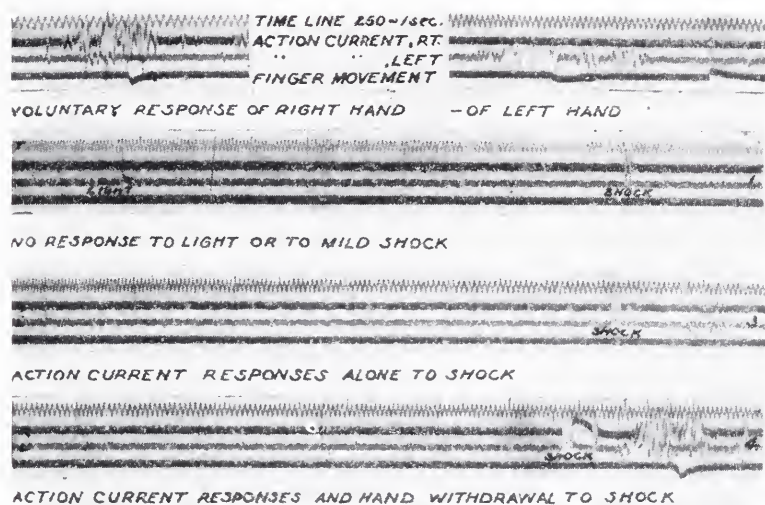


FIG. 4. Samples of records of action currents, overt movement, light stimulus and shock stimulus.

of the wave forms of the two signal circuits. This dissimilarity was achieved by the use of one tube having a high and another tube having a low plate resistance. The former was used in the signal circuit for the right hand and gave a sharp deflection; the latter was used for the left hand and gave a shallower deflection. The wave forms of the overt responses are shown in Fig. 4.

Provision for making or breaking the input circuit was made in the following manner. A rubber glove was slipped over *S*'s hand to insulate him from the circuit. A short piece of metal-conduit, tinned-brass braiding, fashioned to resemble the fingertip of a glove, was slipped over the end of the gloved middle

finger. On the arm of the chair was placed a metal plate of flattened, tinned-brass braiding. The finger completed the input circuit as it rested on the braiding. This arrangement was chosen rather than telegraph keys upon which to rest the fingers, since the latter often introduced artifacts due to differences in spring tension.

Responses also were recorded in terms of action currents from the extensor digitorum communis muscle. Surface electrodes were used for recording, each pair consisting of two thin brass strips 10 x 75 mm., 6 mm. apart, covered with Canton flannel saturated with concentrated salt solution. The electrodes for each arm were placed the same distance distal to the lateral epicondyle, usually 5 to 7 cm.

The stimulus to be conditioned was a brief flash of light from a 2.8-volt focusing-type flash-light bulb. This flash lasted about 100 ms. and preceded the shock by 216 ± 4 ms. This time interval was controlled by a compound pendulum (Fig. 2). The pendulum was held in place by an electro-magnet, and was released by throwing a double-circuit key switch. At the same instant the operation of this switch completed the circuit for the light. When the pendulum had fallen for 100 ms. it struck a trip switch which broke the light circuit. At the bottom of the pendulum swing, another trip switch was struck to complete the circuit for the condenser discharge to *S*.

The source of shock was a variable condenser with a range of .001 mfd to 8 mfd, charged from a source of direct current capable of supplying any voltage from 0 to 300. These ranges represent the upper and lower limits of shock available. A potentiometer and single-pole double-throw switch permitted adjustments of the shocks so that they would be sensed as equal for both hands at any strength of shock. The condenser was charged and discharged by means of a double-pole, double-throw switch.

S was in a separate, light-proof, semi-soundproof room. To eliminate all sound clues, water was permitted to run from a water tap into the sink in the experimental room. The noise thus produced covered a range of frequencies wide enough to mask effectively all noises caused by the apparatus or *E*.

Each experimental session lasted about one hour. Great care was exercised to avoid any disturbances of the action current lines due to tension on the part of *S*. To determine the degree of relaxation of *S*'s arms *E* listened in on the action current circuits during the entire experiment.

The following instructions were read to *S*:

I will put out the light to make the room dark. At times a light will flash. The intervals between these flashes of light will vary in a random order. You are to do nothing but sit, with your hands resting naturally on the metal plates.

Records were taken at each presentation of the flash of light. The purpose of this series was to test *S* for any possible tendency to respond to the light alone.

Then the following instructions were read:

This time you are to sit as before, with both hands resting on the metal plates. The light will flash as before. On the first flash, raise your right hand only; on the second flash, raise your left hand only; on the third flash raise both hands.

Records were taken at each presentation of the light for the purpose of obtaining a record of the response of each hand separately, to insure unquestioned identification of the responses in the records.

Next a series of voluntary reactions were recorded. The instructions were as follows:

Rest your hands on the metal plates. There will be no shock at any time. At times a light will flash. When the flash appears, raise both hands quickly. Put the hands back in place again. Keep your arms as relaxed as possible. Move your hands only when the light flashes.

Then the shocks were adjusted so as to be sensed as equal for the two hands. They were first given at sub-threshold strength, then gradually increased. *S* was told to report as soon as any slight shock was felt. If the shock was sensed in only one hand, or as stronger in one hand, adjustments were made with the potentiometer and single-pole double-throw switch, and the series was again given from sub-threshold strength to the point of perception of shock. This was repeated until the shocks appeared in both hands at the same point in the series and were sensed as equal for the two hands. Then the shocks were increased in equal steps up to the limit of *S*'s tolerance, *i.e.*, as great as he could be

persuaded to endure. During this increase *S* was instructed to note whether the shocks still were felt as equal in both hands. Subjective equality of shocks was sought because of the possible effect on the relative latencies of the two hands. The fact that the right hand responded first consistently, for example, might have been due to a greater shock to that hand rather than to any physiological factor unless the shocks were so controlled. That is, lead of response may have been a function of the relative strength of the shock. Objective equality of shock, as measured by the ammeter, was not sought. A more convenient and more justifiable criterion was the subjective equality: how did *S* sense the relative strength of the shocks to the two hands?

When the shocks thus had been equated, the establishment of the conditioned responses was begun. The following instructions were read:

Rest your hands naturally on the metal plates. Relax your arms throughout the series. At times a light will flash. Each flash will be followed quickly by a shock which should cause your hands to withdraw. Whenever your hands move put them back on the metal plates and wait for the next flash of light. Do not try to avoid the shock. The shock will come no matter where your hands are.

The room was darkened, the door closed, and the water turned on. A constant interval of 216 ms. was maintained between the light and the shock. The paired light-shock stimuli were presented at intervals of 10, 20, 30, or 40 sec., the intervals varying in a random order. *S*s were stimulated until conditioning was established or until at least 50 paired stimuli had been given. This constituted one experimental session.

Conditioning was not considered established unless at least five consecutive finger withdrawals occurred to light alone. This could be determined, without questioning or disturbing *S* in any way, by means of the ear phones connected to either the signal circuit or the action current amplifier auxiliary. The former indicated overt responses in either hand; the latter indicated the presence of action currents. Thus *E* could tell whether responses were occurring in terms of action currents alone, or whether overt responses were accompanying the action currents. These devices facilitated the procedure by enabling him to know what

was occurring. It enabled *E* to know just when to stop the recording for each separate record, and when to stop recording at the end of an extinction series.

During the series of presentations of paired stimuli, occasional records were taken when the light alone was presented. If no responses occurred, the dual stimulation was continued. When definite overt conditioned responses did appear for five consecutive times, conditioning was established further by presenting the paired stimuli several times. A continuous series of records then was taken of responses to the light alone. This was continued not only to the point where overt responses dropped out, but to the point where even the action current responses ceased, and then for six presentations of light alone beyond that point. This was done to make sure that extinction had been effected.

Although the above procedure was found adequate for the investigation of most of the problems formulated, it was found that the development of the conditioned response could not be clearly demonstrated thereby. Therefore, it was necessary to employ a supplementary technique which varied from the former only in that an interval of 505 ± 4 ms. rather than of 216 ms. was used. This longer interval between the light and shock was chosen in order to get a picture of the development of the conditioned response by capitalizing on its characteristics as an anticipatory response. To do this, the interval between light and shock had to be lengthened to an amount greater than the latency of the conditioned response. This gave the early stages of the conditioned response a chance to reveal themselves. Upon repetition of paired stimuli, responses began to appear during the interval between the light and shock. This series necessitated taking a record at each presentation of the stimuli. For this reason *Ss* chosen for this series were those who had shown themselves to be conditionable. Care was taken not to establish the conditioned responses too rapidly.

After each experimental session *S* was given the following questionnaire to fill out. When the responses had been written he was questioned further to make sure that he had understood the questions and had answered them correctly.

Questionnaire given to the subject after an experimental session

Name

Date

Handedness

1. Intensity of the light during shock stimulation showed:
 - a. constancy
 - b. progressive decrease
 - c. progressive increase
 - d. irregular variation
2. Intensity of the light during extinction showed:
 - a. constancy
 - b. progressive decrease
 - c. progressive increase
 - d. irregular variation
3. Strength of shocks was:
 - a. equal for both hands
 - b. stronger for the right hand
 - c. stronger for the left hand
4. Reaction towards the shocks was:
 - a. indifference
 - b. unpleasantness
 - c. anticipation
 - d. fear
 - e. avoidance (keeping hands raised)
5. Which hand responded sooner:
 - a. neither
 - b. the right
 - c. the left
 - d. uncertain
6. Which hand had the greater response:
 - a. neither
 - b. the right
 - c. the left
 - d. uncertain
7. Certainty as to when shocks occurred:
 - a. certainty
 - b. uncertainty
8. Response to light alone:
 - a. yes
 - b. no
9. Was the response to light alone:
 - a. voluntary
 - b. involuntary
10. Attitude following response to light alone:
 - a. surprise
 - b. amusement
 - c. disgust
 - d. neutrality
11. Resolve not to respond to light alone:
 - a. yes
 - b. no

12. Success of this resolve :
 a. yes
 b. no

TABLE I. *Number of Ss with whom conditioning was attempted*

Handedness	Men	Women	Total
Right	15	12	27
Left	12	8	20
Ambidextrous	5	4	9
Total	32	24	56

TABLE II. *Number of Ss conditioned*

Handedness	Men	Women	Total
Right	11	3	14
Left	2	2	4
Ambidextrous	2	1	3
Total	15	6	21

III. Subjects. Fifty-six Ss, ranging in age from 20 to 38 yrs., were studied. Of this number 21 were conditionable according to the criteria set up in this study. The following tables summarize the information with regard to the Ss.

IV. Results and discussion. For clearness of presentation, the statement of results will follow the order in which the specific problems were stated in the introduction.

Characteristics of the conditioned hand withdrawal as recorded by the action current technique. The type of records obtained is illustrated in Fig. 4. The upper record in this figure is that of the voluntary response to the light stimulus. The first half of the record is for the right hand, and the second half for the left hand. It may be noted that for each hand the action currents appeared before the overt movement. In the record for the right hand, it may be seen that small action currents appeared in the left forearm. It is evident that the overt responses of the two hands, as recorded by the lowest line in the record, easily can be distinguished by the form of the deflection, the right hand deflection being much sharper than the left.

In the second record, which is No. 1 of the series, is shown the recording of the light stimulus, and of a mild shock to S.

The third record shows the result of a slightly stronger shock, which evoked a slight action current but no overt response. In the fourth record, the shock was strong enough to produce an overt response. The action currents and overt response of the left hand can be seen to precede slightly those of the right hand.

Before giving sample records illustrating the actual building up of a conditioned response, it would seem wise to state the criteria of conditioning. Decision as to whether a *S* has been conditioned or not necessarily must be somewhat arbitrary. Conditioning usually has been defined in terms of a minimum number of consecutive conditioned responses. Some writers have made three the required number, but classification would differ with the method of recording responses. Action current records often showed responses when overt responses were absent, or even when *S* thought he was no longer responding, at the end of an extinction series. That is, he was definitely responding in terms of action currents, when no overt response or subjective awareness of reaction was present. In this experiment, a conditioned response was not considered thoroughly established until five consecutive responses to light alone were obtained.

Heretofore the recording of the conditioned hand withdrawal has been in terms of overt response. It was either present or absent, and what occurred with respect to muscle action in the absence of overt response could only be guessed. Since it was unlikely that all the motor units of a muscle were simultaneously involved when the overt response first appeared in the process of establishing the conditioned response, or that they ceased functioning immediately upon extinction of the overt response, the assumption was that some gradation was present in the degree of contraction. The truth of such a supposition could be shown by means of the action current technique.

While all of the exploratory work and most of the experimental results obtained on extinction were done with an interval of 216 ms. this interval could not be used for the study of the development of the conditioned response. The time interval was changed to that of 505 ms. which is longer than the obtained latencies of the conditioned response. This made it

possible to take advantage of the fact that by nature the conditioned response is anticipatory. It is a reaction built up in the experimental situation by virtue of repetition of the paired light-shock stimuli. After sufficient repetition, *S* began to anticipate the shock upon perceiving the light. The anticipatory responses, which were conditioned responses, would then in time follow the light but precede the shock. Fig. 5 and Fig. 6 show the process

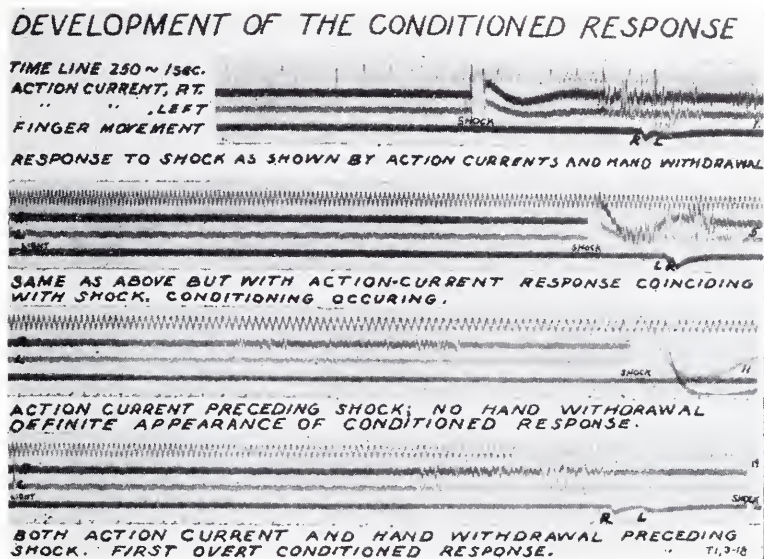


FIG. 5. Sample records of the development of the conditioned response.

of development. Unfortunately it was impossible to present the whole series of 80 records obtained. The figure at the right end of each strip of film indicates the number of the record.

Record 1 (Fig. 5) shows that no response preceded the shock, and that action currents and overt responses of both hands followed the shock. It is not possible to tell exactly when the action currents in response to the shock began, but it is clear that the right preceded the left overt response. Record 5 shows no response prior to the shock. Nevertheless there is evidence that conditioning is beginning to manifest itself, in that the initiation of action currents coincides with the shock, and the overt response

latency is too short to be considered as a response to shock alone. There are several similar records in the series. Record 11 is a clear example of how conditioning is revealed in its anticipatory characteristics as incipient muscular contractions (small action currents) prior to the shock. The action currents appeared with no evident overt response and ceased entirely before the shock. Then the shock occurred, and another response occurred, this time in terms of both action currents and overt response. Unfortunately, the record was too long to permit all of it to be shown,

FURTHER DEVELOPMENT OF THE CONDITIONED RESPONSE

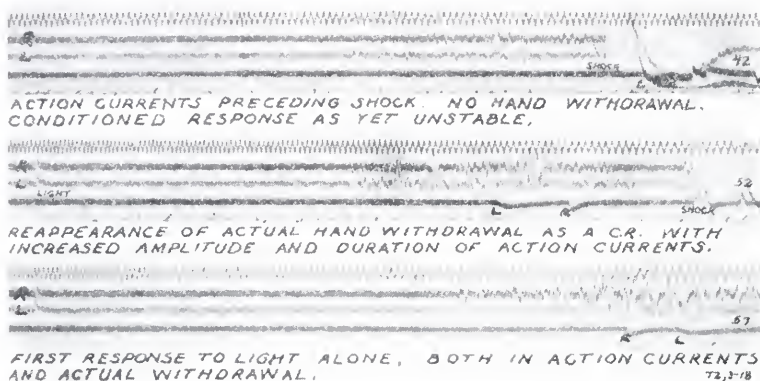


FIG. 6. Sample records of further development of the conditioned response.

but the general picture is that of the response to shock in Record 1. The first overt conditioned response was obtained in Record 19. The conditioned action current response already had ceased by the time the shock occurred. A definite overt response (not shown) was again elicited by the shock.

Fig. 6 shows the further development of the response. Record 42 clearly shows that the establishment of a conditioned response is not always a steady, unvarying progression. During development the overt response may precede the shock, then recede in time behind the shock, then precede it again, until finally conditioning is established to the point where it definitely and constantly precedes the light as an overt conditioned response. Record 52 indicates the reappearance of the overt response pre-

ceding the light. Record 57 was the first record taken with light alone as the stimulus, a response which proved to be the first of a series of 14 consecutive conditioned responses.

A different picture of development was shown by other Ss. The records of FE (Fig. 8) illustrate the point. Here is shown a consistent tendency for the conditioned response to move forward progressively in time. Record 5 indicates a response to shock

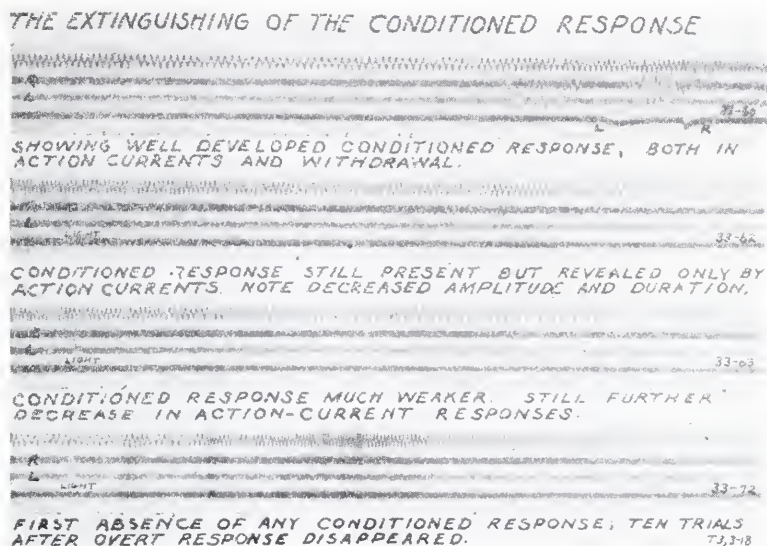


FIG. 7. Sample records during extinction.

only. In Record 11, the action currents preceded, while the overt movement almost coincided with the shock. This showed that the response was actually in anticipation of the shock. Record 20 is an example of the action current and overt response preceding the shock. In Record 21 the action currents and overt response have preceded the shock still further.

Another of the aspects by which the development of the conditioned response manifested itself was that of an increase in the amplitude of the action currents. Since *Richter* (7), and *Travis* and *Lindsley* (9) have shown that a definite correlation exists between the magnitude of action currents and the magnitude of a voluntary muscular contraction, the increased action current

amplitudes found in the present study undoubtedly mean that there was a corresponding increase in the intensity of muscular contraction. However, no quantitative measurement was performed on these records, since the duration of the response was often limited by the appearance of wide shock deflections, and since the individual amplitudes were unmeasurable because of the superposition of conditioned and unconditioned responses, and of right and left responses upon each other. It was therefore decided to rely upon inspection and to present the results thereof. Fig. 5 and Fig. 6 illustrate the tendency for the amplitude of the action currents to increase during the development of the conditioning.

TABLE III. *The number and per cent of cases in which the various characteristics of the conditioned response appeared during establishment and extinction*

Characteristic	No. of cases	Per cent of cases
During establishment:		
Progressive increase of size of action currents	7	70
Appearance of action currents prior to appearance of overt response	7	70
Progressive decrease of response latency	2	20
Marked fluctuation of response latency	3	30
During extinction:		
Progressive diminution of size of action currents	24	96
Progressive increase in response latency	9	60
Appearance of action currents after overt responses ceased	24	96
	Range	Mean
Number of action current responses following disappearance of overt response	0-12	3.6

After the development had taken place, the conditioned response was found to enter a period of relative stability during which each successive presentation of the light alone caused a well formed overt response. The length of this period of stability varied from individual to individual. This was probably due to some of the following factors: the ease with which conditioned responses could be established, the number and strength of shocks administered, and perhaps the emotionality of *S*. The range of the number of conditioned responses was from five to 96. The

lower limit of five was determined by the definition of established conditioning set up in this experiment.

Extinction of the conditioned response presented a reversal of the order of the events shown in its development. Upon repeated presentation of the light alone, the action currents accompanying the overt response gradually decreased in magnitude. In time the

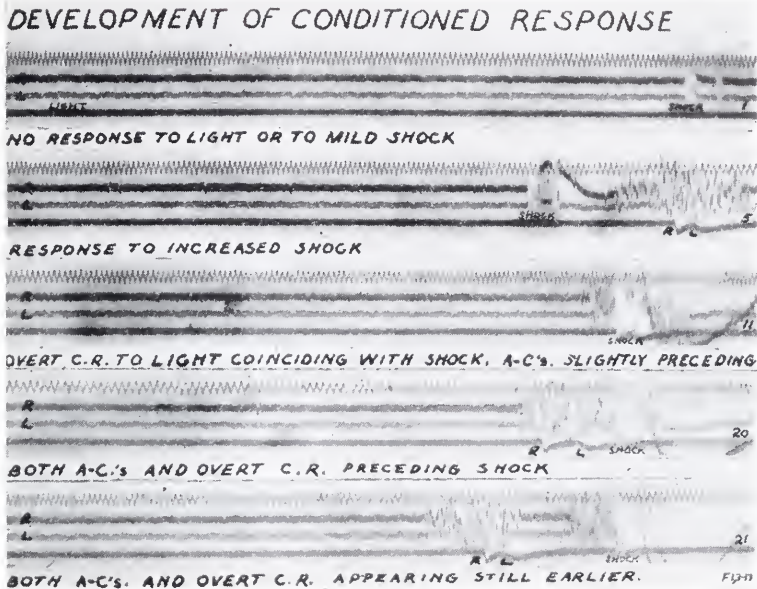


FIG. 8. Records of development.

overt response dropped out. For several presentations of light beyond that point, the action currents appeared without overt response being present. These action currents progressively diminished in size, until the point was reached where they too disappeared. In all cases, at least six records were taken beyond that point to make sure that extinction had been achieved. Fig. 7 and Fig. 9 illustrate the point. The persistence of action currents after the overt response had disappeared is less in Fig. 9 than in Fig. 7. Differences of this sort depend upon depth of establishment, the ease with which *S* can be conditioned, and other related factors.

Another way in which extinction was shown to be the reverse of establishment was in response latency. About one-half of the *Ss* showed a definite trend toward increased latency of response as extinction progressed. This is evidently the reverse of the trend shown in establishment.

It is interesting to note that as extinction progressed the

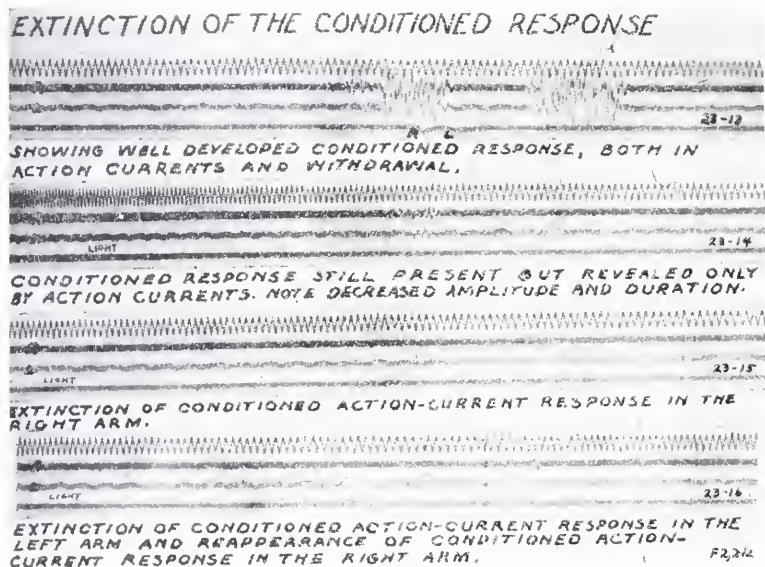


Fig. 9. Records of extinction.

response often showed tendencies toward instability. Toward the very end of the extinction series, it was found that in some cases conditioned responses failed to occur for two or three presentations, followed by reappearance of the conditioned response in subsequent records. This instability of the response toward the end of extinction, together with the dropping out of the overt response before the action currents disappeared, and the general progressive diminution in amplitude of the action currents indicate again that the formation and decay of the conditioned response must be interpreted in terms of graded muscular contraction. Extinction therefore may be termed, in general, the reverse of the process of establishment.

The preceding discussion has been expressed in generalities for purposes of exposition. These results will now be stated in greater detail. In Table III is shown the frequency with which these characteristics of establishment and extinction occur. The Vincent curve of the smoothed response latency values (Fig. 10) shows a trend toward increased latency during extinction.

In three *Ss*, no records of development of the conditioned response were obtained. In each of these *Ss*, conditioning was

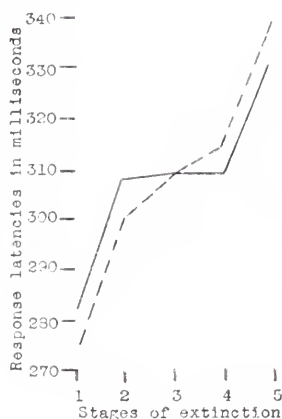


FIG. 10. Vincent curves of smoothed response latencies during extinction of the conditioned hand withdrawal. Solid line, all 15 *Ss* included; broken line, omitting six *Ss* who did not follow trend.

established easily and rapidly, and each of them showed action currents after the overt response had dropped out in extinction. This indicates that when *S* was especially susceptible to conditioning, due to such factors as extreme sensitivity, or to having been previously strongly conditioned, establishment occurred too rapidly for the development to be recorded. Conversely, in *Ss* in whom action currents ceased with cessation of overt response, the establishment was effected with greater difficulty, and the picture of establishment was more easily obtained.

Similarly, exceptions were found to the trends of decrease of latency during establishment and increase of latency during extinction. Although, on the whole, the Vincent curve for the whole group during extinction showed the trend toward increased

latency as extinction progressed, six of nine *Ss* failed to show this trend. In two *Ss* the latency decreased during the first half of the extinction series and then increased. In the other *Ss* the latency trend varied irregularly about the central tendency. Explanation of these differences in latency trends can only be conjectured. Possibly it may be explained in terms of extreme apprehension for the shocks or slow adaptation to the experimental situation. The exceptions to the trend toward a decreased latency as the conditioned response became established possibly may be accounted for in terms of extreme rapidity of establishment. The response developed so quickly that when it appeared it did so with an already shortened latency. In the remaining *Ss* who did not show this trend toward decreased latency, marked fluctuations of response latency were evident. This variability indicated the instability of the response in its early stages.

The exceptions to the general trend of progressive increase and decrease in amplitude of action currents during establishment and extinction respectively, and those cases in which overt responses were not preceded by action currents alone during the development, or succeeded by action current responses alone during extinction, are probably the result of factors underlying extreme rapidity of establishment or extinction.

The remaining characteristic of the conditioned hand withdrawal which was examined was the relationship between extinction and the "action current overt response interval". The latter expression is used for the sake of brevity to refer to the difference in time between appearance of action currents and appearance of overt response. No clear-cut, general relationship was found for the group of *Ss* as a whole. However, in five of the 12 *Ss* whose records could be used for this part of the study, a definite trend existed as can be seen in Fig. 11. This relationship is that as extinction progresses the interval increases. This phenomenon can not be explained in terms of any facts shown by previous studies. Experiments now being conducted in the University of Iowa laboratories seem to indicate that there may be some relationship between the action current overt response interval and speed of contraction.

Differentiation of the conditioned from the voluntary response.

As mentioned earlier in this paper many criticisms have been directed against considering the conditioned hand withdrawal as a true conditioned response. It was deemed desirable to determine the validity of these criticisms. This was done by comparing and contrasting voluntary hand withdrawals with conditioned hand withdrawals, and by determining whether the conditioned hand withdrawal possessed the same characteristics as other widely accepted conditioned responses.

Differentiation between the conditioned and the voluntary hand withdrawal is clearly indicated in the way in which the former developed in terms of action currents. It has been noted

TABLE IV. *The averages of the means and SDs of action current and overt response latencies of the conditioned and voluntary hand withdrawal*

Resp.	No.	Overt Response				Action Current Response			
		Mean		SD		Mean		SD	
		Left	Right	Left	Right	Left	Right	Left	Right
Cond.	18	336.7	321.2	40.6	43.2	279.7	281.2	51.0	44.4
Vol.	20	323.9	311.4	39.9	40.2	274.3	264.4	41.8	41.6
Shock	9	121.8	119.0	15.4	13.4	62.2	63.1	10.1	11.5

that the conditioned response was built up as a graded muscular contraction, increasing in degree until the overt response appeared.

Extinction presented the reverse picture, namely, progressive diminution of degree of contraction to the point of complete absence of response (Figs. 5, 6, 7, 8, 9). Such a process of growth and decline in degree is never presented by the voluntary response: the first voluntary response is like the last or any intermediate response in its general characteristics. For the sake of economy, no records of a voluntary response are presented other than the upper record in Fig. 4, since any single record of voluntary responses cannot be distinguished from that of the ordinary, firmly established conditioned response. Neither Fig. 5, Record 19, nor Fig. 6, Record 57, nor yet Fig. 8, Record 21, differ in appearance from a voluntary response, had the shock been absent. Differentiation in this respect does not rest on single records, nor on any method of analysis of the form or other characteristics of a single response. Comparison must rest upon

the entire series of records. Differentiation is clearly revealed through the characteristics of development and decay in the conditioned response.

A second comparison could be made of the means and standard deviations of the response latencies. Table IV present such comparisons. Response to shock is also presented, although the records are rather meager.

These results indicated that, when latencies are considered in terms of the mean or standard deviation of an entire series, the conditioned and voluntary response did not differ. However,

TABLE V. *The mean of the averages and SD of the action current-overt response intervals in the conditioned and voluntary responses*

Response	No. subjects	Left Hand		Right Hand	
		Mean	SD	Mean	SD
Conditioned	16	56.6	18.5	58.7	19.3
Voluntary	19	52.7	12.5	53.8	11.5

TABLE VI. *Average conditioned response latencies obtained with the respective intervals of 505 and 216 ms. between light and shock, on eight S's*

Interval in ms.	Overt Response		Action Current Response	
	Left	Right	Left	Right
505	304.4	369.1	306.4	309.0
216	336.7	321.2	279.7	281.2

another method of treating response latencies for comparison is that of constructing Vincent curves for successive periods for both types of response. The Vincent curve for the conditioned response latencies already has been given in Fig. 10. The Vincent curve for the voluntary response latencies, constructed in the same manner as that for the conditioned response, is presented in Fig. 12. A comparison of the Vincent curves for the conditioned and voluntary responses reveals some interesting facts. While in the voluntary response there was no observable change in latency there was some such change for the conditioned response. While there were individual exceptions to this trend for the smoothed curves of the conditioned response, on the other hand, not one *S* showed any such trend in the voluntary response. In general, there was indication that differentiation occurred

between the conditioned and the voluntary response with respect to latency trends, although there were individual exceptions.

A comparison was then made with respect to action current overt response intervals. The results are given in Table V. Again there was no differentiation between the voluntary and

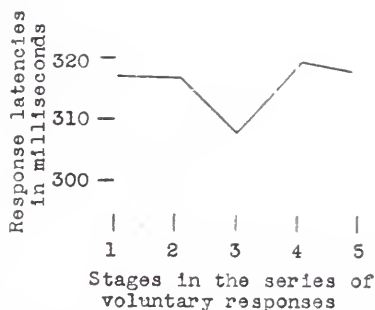


FIG. 11. Vincent curve derived from smoothed response latency values during a series of voluntary hand withdrawals to light. 11 Ss.

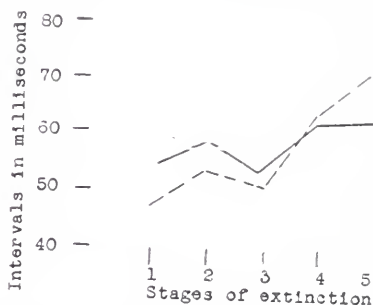


FIG. 12. Vincent curves of smoothed action current overt response interval values during extinction of the conditioned hand withdrawal. Solid line, all 12 Ss; broken line, five Ss who showed definite trend.

conditioned response when averages for the entire series were considered. The means and *SDs* were substantially the same. A comparison was then made of the Vincent curves (Fig. 13) for the action current overt response latencies in order to reveal any existing trends. As the series progressed, no trend toward an increase of interval could be observed, either for the group as a whole or for any single *S*. It will be recalled that there

was some such trend in the conditioned response, and that in five out of 12 *SS* such a tendency was definite (Fig. 11).

Because of the fact that in one procedure an interval of 216 and in the other an interval of 505 ms. was used between the light and the shock, results were obtained which made it possible to note the effect of differences in interval upon conditioned response latency. These results are summarized in Table VI, and include only the data obtained on *SS* who were used in both procedures. The tendency existing was toward a longer response latency in connection with the 505 ms. interval. This agrees substantially with *Hilgard's* findings (2) on the conditioned eyelid reaction: shortening the interval between conditioned and unconditioned stimulus shortened somewhat the conditioned response latency.

Thus far the problem of differentiation between the voluntary and conditioned responses has been investigated on the basis of objective records. Important evidence also comes from the subjective report of *S*. One of the major criticisms against the hand withdrawal is that it employs a response mechanism which is subject to voluntary control. This of course can not be gainsaid. However, it does not follow that a mechanism which can respond voluntarily always does so. Although the terms are somewhat ambiguous, a response may be characterized as involuntary if *S* responded without previous intention to respond, if *S* was unaware that he has responded, and if the response could not be inhibited.

Information (Table VII) bearing on these considerations was derived from the questionnaire. All *SS* reported that they responded involuntarily, and that there had been no intention on their part to respond. From the description of the procedure above, it will be recalled that *S* could not in any way avoid the shock. There was no point in his voluntarily withdrawing the hand, since no purpose would be thus served. Seven *SS* reported reactions of surprise, amusement or disgust because they had responded to the light alone; 11 *SS* reported neutrality. Where the former reactions occurred, the presumption is that no intention to respond had been present. Five *SS* reported a determina-

TABLE VII. *Number and per cent of responses of conditioned subjects to the questionnaire items*

	No.	Per cent
1. Intensity of light during shock stimulation		
a. constancy	8	44
b. progressive decrease	0	0
c. progressive increase	0	0
d. irregular variation	10	56
2. Intensity of light during extinction		
a. constancy	3	17
b. progressive decrease	2	11
c. progressive increase	0	0
d. irregular variation	13	72
3. Strength of shocks		
a. equal for both hands	14	88
b. stronger for the right hand	2	12
c. stronger for the left hand	0	0
4. Reaction toward shocks		
a. indifference	0	0
b. unpleasantness	3	19
c. anticipation	8	50
d. fear	5	31
e. avoidance (keeping hands raised)	0	0
5. Initiation of response		
a. simultaneous	10	56
b. right lead	2	11
c. left lead	2	11
d. uncertain	4	44
6. Amount of response		
a. equal for both hands	4	44
b. greater for right hand	7	39
c. greater for left hand	4	22
d. uncertain	3	17
7. Certainty as to when shocks occurred		
a. certain	18	100
b. uncertain	0	0
8. Response to light alone		
a. yes	18	100
b. no	0	0
9. Nature of response		
a. voluntary	0	0
b. involuntary	18	100
10. Attitude following response to light alone		
a. surprise	2	11
b. amusement	5	28
c. disgust	0	0
d. neutrality	11	61
11. Resolve not to respond to light		
a. yes	5	28
b. no	13	72
12. Success of this resolve		
a. yes	0	0
b. no	18	100

tion not to respond, but nevertheless did respond. Furthermore, in order to test the voluntary nature of the response, several *Ss*, among whom were two ranking members of the psychology department, entered the experiment with a specific determination not to respond. Despite these unfavorable attitudes, conditioning occurred in each instance.

A still further proof that the response was non-voluntary in nature is provided by *S's* awareness or unawareness that the response had occurred. Earlier in this paper it was shown that there were definite conditioned action current responses, even when no overt movement occurred, and that some of these action current responses were of low amplitude and short duration. These indicate the presence of extremely slight contractions,

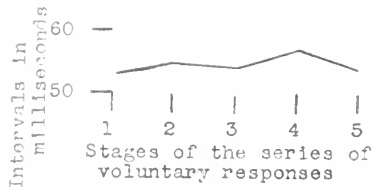


FIG. 13. Vincent curve derived from smoothed action current overt response interval values for the voluntary hand withdrawal. 10 *Ss*.

which, however, were definite conditioned responses. As workers in the field of chronaxy and electromyography know, it is possible for an *S* to have very slight muscular contractions of which he is totally unaware. These phenomena commonly occurred during the course of the present investigation, and are illustrated by the records of one case in Fig. 14. This *S* reported that he had responded only once, in any way whatever, to light alone. Record 16 shows that he did respond once, with the left hand overtly, and with both arms in terms of action currents, but the other records show that he had several conditioned responses, although not overtly. These responses are rather slight, and of short duration, especially Records 15 and 17, which accounted for *S's* lack of awareness of them. Similarly, the other records indicated definite conditioned responses in terms of action currents. Moreover, six other records not shown here, from the same series, show the

same phenomenon. In other words, *S* was aware of but one of 11 definite responses. Were this a voluntary response, no such lack of awareness could have occurred.

The conclusion to be drawn from the subjective reports is that the response was involuntary, that it could not be inhibited, and that responses occurred often without awareness of their occurrence on the part of *S*.

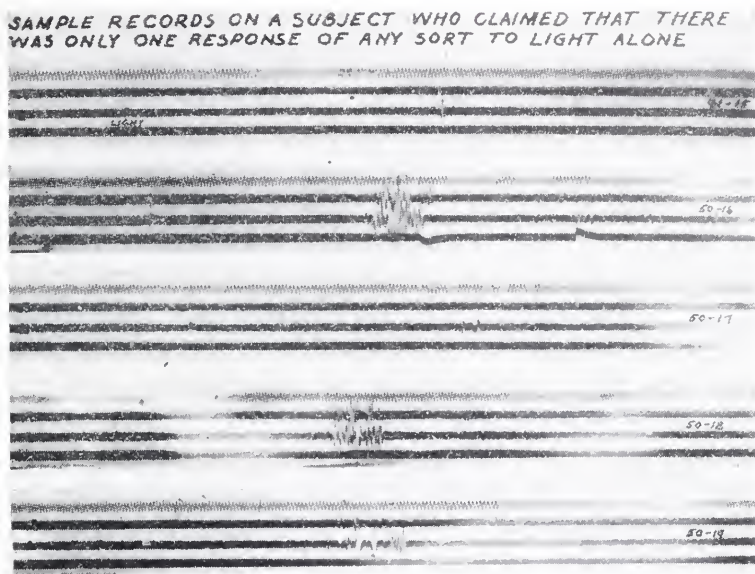


FIG. 14. Slight muscular contractions of which *S* was totally unaware.

Relation of handedness to differences in the response latencies of the two hands when simultaneously conditioned. These differences were expressed in terms of action current latencies, overt movement latencies, action current overt response intervals, and the frequency with which the preferred and nonpreferred hand led. A comparison was also made with similar measures obtained from voluntary response records.

This problem has been attacked through the use of voluntary responses by Orton and Travis (5), Metfessel and Warren (3), and Travis, Tuttle and Bender (10). The specific problem for investigation was: do action currents and overt responses appear

in the preferred hand before they appear in the non-preferred hand, or does the reverse, or neither, hold true? *Orton* and *Travis* required *S* to respond to a signal with the two hands simultaneously. They found the action current lead to be, in general, in the preferred hand. *Metfessel* and *Warren* found the lead to be in the non-preferred hand, and explain their results as being due probably to over-compensation of the less-used hand in an attempt at simultaneous movement. *Travis*, *Tuttle* and *Bender* decided that conflicting results occurred in the previous studies because the lead is to a large extent a function of the instructions given to, and the tasks imposed upon, the *S*.

Because of these conflicting results, it was felt desirable to attack the problem in an experimental situation which would eliminate both the factor of instructions to *S* and that of voluntary control. The conditioned response situation does both. As stated previously, both hands were conditioned simultaneously, with shock stimuli which were sensed as equal for both hands. Although conditioning was attempted on 27 right handed, 20 left handed, and nine ambidextrous *Ss*, usable records were obtained on 11 right handed, two left handed, and three ambidextrous *Ss*.

Table VIII presents the means and standard deviations of both action currents and overt response latencies in the conditioned response for right handed, left handed and ambidextrous *Ss*. In these means, the preferred hand did not show a significantly larger or smaller value than did the non-preferred hand, for either the conditioned or the voluntary responses. In average latencies for individual *Ss*, four out of nine showed a smaller value for the preferred hand for the conditioned response; three out of seven showed a smaller value for the voluntary reaction.

Table X gives the means of the average action current-overt response latencies. No significant differences were found between the two hands, for the conditioned or voluntary responses. For individuals, the shorter value was found in five out of 10 cases for the preferred hand for the conditioned response, and three out of nine for the voluntary response.

The Pearson product-moment coefficients of correlation be-

tween the action current and overt response latencies for individuals were, with one exception (of .86), over .90 for both the conditioned and the voluntary responses.

TABLE VIII. *The means of the average and SD of the response latencies in terms of action currents and overt response in the conditioned hand withdrawal for 12 right handed, three left handed and three ambidextrous Ss*

Handed- ness	No.	Overt Responses				Action Currents			
		Left hand		Right hand		Left hand		Right hand	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
R	11	301.5	30.6	306.3	33.7	269.1	39.4	272.2	39.4
L	3	357.1	60.4	365.2	59.8	341.3	84.6	331.8	66.4
A	3	327.1	47.4	326.9	48.6	269.3	38.7	266.5	39.1

TABLE IX. *The means of the averages and SD of the response latencies in the voluntary response for 11 right handed, seven left handed, and two ambidextrous Ss*

Handed- ness	No.	Overt Responses				Action Currents			
		Left hand		Right hand		Left hand		Right hand	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
R	11	301.8	35.3	294.3	35.1	252.5	36.3	256.1	36.7
L	7	337.3	48.4	337.8	49.6	281.2	52.0	277.8	51.3
A	2	317.1	35.5	313.1	35.1	258.9	34.4	258.7	23.2

TABLE X. *The means of the averages and SD of the action current-overt response intervals for each hand for the conditioned and voluntary responses, for right handed, left handed and ambidextrous Ss*

Response	Handedness	No.	Left hand		Right hand	
			Mean	SD	Mean	SD
Conditioned	right	12	56.4	18.4	55.3	19.4
Conditioned	left	2	64.3	25.7	74.1	24.5
Conditioned	ambidextrous	3	57.9	10.5	57.0	11.0
Voluntary	right	10	49.9	13.0	49.1	11.5
Voluntary	left	7	54.8	12.4	60.2	12.4
Voluntary	ambidextrous	2	58.3	10.9	54.5	8.5

When individual or group averages were derived, no significant differences were found between the reactions of the two hands. However, these averages in a sense might tend to disguise the true facts concerning the leading hand.

For this reason, another method of analysis was used. This involved finding the per cent of responses in which the right or left hand led, with relation to handedness. This was done in

TABLE XI. *The number of right handed left handed and ambidextrous Ss who showed a right overt response or action current lead in more than 60, 70, 80 and 90 per cent of the responses, based on 10 or more conditioned or voluntary responses*

Per cent of right leads	Overt Responses						Action Current Responses					
	Cond. resp. Handedness			Vol. resp. Handedness			Cond. resp. Handedness			Vol. resp. Handedness		
	R	L	A	R	L	A	R	L	A	R	L	A
60	0	0	1	1	3	1	3	1	2	0	3	0
70	0	0	0	1	2	0	0	1	1	0	3	0
80	0	0	0	0	1	0	0	0	0	0	2	0
90	0	0	0	0	0	0	0	0	0	0	0	0
No. cases	11	2	3	10	7	2	10	2	3	10	7	2

TABLE XII. *The number of right handed, left handed and ambidextrous Ss who showed a left overt or action current lead in more than 60, 70, 80 or 90 per cent of the responses, based on 10 or more conditioned or voluntary responses*

Per cent of left leads	Overt Responses						Action Current Responses					
	Cond. resp. Handedness			Vol. resp. Handedness			Cond. resp. Handedness			Vol. resp. Handedness		
	R	L	A	R	L	A	R	L	A	R	L	A
60	7	2	1	7	3	0	4	1	1	6	2	0
70	7	1	1	5	2	0	4	0	1	4	1	0
80	6	0	1	3	1	0	4	0	0	4	1	0
90	1	0	0	2	1	0	3	0	0	1	0	0
No. cases	11	2	3	10	7	2	10	2	3	10	7	2

terms of action currents and overt responses, for both the conditioned and voluntary reactions. The results are given in Tables XI and XII. These tables are constructed so as to show in detail to what extent, for example, the right handed Ss gave response leads in more than 60, 70, 80, or 90 per cent of the records. The results showed no definite relationship between response-lead and handedness. However, the number of cases was inadequate as a basis for any final conclusions.

None of the methods of analysis revealed any clear cut relationships between handedness and response lead, response latencies, action current overt response intervals, ease of conditioning, or rate of extinction.

V. Summary. The following specific problems were set up for investigation:

1. The development and extinction of the conditioned response in terms of progressive increase and decrease of action currents, action current latencies, overt movement latencies and the action current overt response interval.

2. Differentiation between the conditioned and the voluntary response in terms of development and extinction, response latencies, the action current overt response interval, and subjective report.

3. Differences in the responses of the two hands when simultaneously conditioned, as related to the handedness of the *S*. These differences were expressed in terms of action current latencies, overt movement latencies, and the action current-overt response interval. Voluntary responses were similarly studied.

The conditioned stimulus was a flash of light. The unconditioned stimulus was a condenser discharge. In one series, the light preceded the shock by 216 and in another, by 505 ms. The shock was applied simultaneously to both hands, and was made subjectively equal for both hands. Records were obtained of the action currents from the extensor digitorum communis muscles of both arms, and of the overt movements of both hands. Usable records were obtained from 18 adult *Ss*.

The records showed that, during establishment, the conditioned response appeared first only in the form of slight muscular contractions and developed to the point where overt movement appeared. Extinction presented a reversal of this order of events. The means and the standard deviations of conditioned and voluntary response latencies were the same. The means and standard deviations of the response latencies to shock were much smaller. The correlations between action current and overt response latencies were .90 or higher. The action current overt response interval was the same for both conditioned and voluntary responses.

Differentiation between conditioned and voluntary hand withdrawal was made by (1) subjective report (2) progressive increase in magnitude of action currents prior to appearance of overt response, during establishment of the conditioned response, and (3) progressive decrease in magnitude of action currents after overt responses ceased, during extinction. In some *Ss*,

differentiation was also shown by a definite trend of increase in the conditioned response latency as extinction progressed, and by a tendency for the action current overt response interval to increase at the end of extinction.

Handedness did not show any general relation to rate of conditioning or extinction, to response latencies, to the action current overt response intervals, or to response leads.

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ACTION CURRENT PATTERNS OF HOMOLOGOUS MUSCLE GROUPS DURING REFLEX ACTIVITY

by

MERVIN PATTERSON

1. Introduction. Hypothetical induction from experimental facts supporting the theory of cerebral dominance suggested the possibility that action current records of reflex activity from the two sides of the body might indicate the dominant of the two hemispheres. This study attempts to test this hypothesis; in addition action current records were examined for evidence of any inter-relationship existing between the same reflexes on opposed sides of the body and for evidence concerning the anatomical and functional order of the reflexes.

According to those who hold to the theory of cerebral dominance, (1) the higher centers of the central nervous system exert a controlling influence over the lower; (2) the preferential use or lead in the function of the peripheral organs of the body is a reflection of the dominance of one cerebral hemisphere over the other. The first part of the theory was originally advanced by *Hughlings Jackson* (7) and recently has been substantiated by a series of studies in which it was shown that the latency and pattern of reflex action current records were changed by depressing or exciting the activity of the cerebral hemispheres (3, 16, 17, 18). The second part of the theory is derived from consideration of cases of aphasia and stuttering; in these cases, interference with the leading or dominant hemisphere as indicated by handedness or tests of peripheral laterality has resulted in aphasia when there is destruction of nervous tissue (24) and in stuttering when there is abnormality of function (15, 19). Since the cerebral hemispheres function asymmetrically and since alteration of the control of the cerebral hemispheres over lower centers results in change in reflex action current records, the hypothesis

was advanced that the asymmetrical functioning of the hemispheres might be manifest in reflex action current records from homologous muscle pairs.

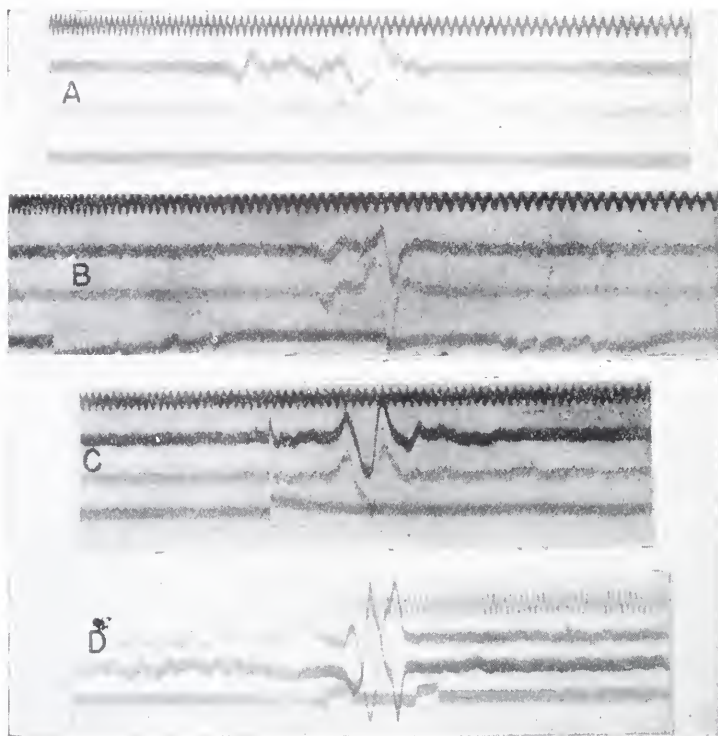


FIG. 1A, human patellar reflex; 1b, human Achilles reflex; 1c, human jaw jerk; 1d, patellar records, dog D. In all records the middle two lines are action current lines, the upper from the right side of the body and the lower from the left. The time lines in each figure represent .001 of a second. The fourth line in each records the instant of administration of the stimulus by an abrupt break in the line. The stimulus was recorded on the action current lines in Fig. 1A by pick-up from contact potential between rod and pendulum. In Fig. 1d the action current records are 180° out of phase, an effect of placement of the electrodes.

Apart from the study of the influence of higher centers on lower reflex centers, evidence was sought in the records taken of any interconnection and interaction existing between the reflex centers themselves. *Wendt* (25) has collected references to the associated crossed extensor reflex in response to percussion

on the patellar tendon. He concludes that from the occasional presence of such an alliance in abnormal conditions the integrating paths from the receptors of one side to the contralateral effectors are of relatively low resistance. He found additional evidence for the close connection of reflex centers in rapid development of a short-latency bilateral response to stimulation of either patellar tendon alone following a period of stimulation of both tendons together; he interprets the crossed response as being of reflex origin. Although *Wendt* has demonstrated interconnection between bilateral reflexes involving homologous muscle

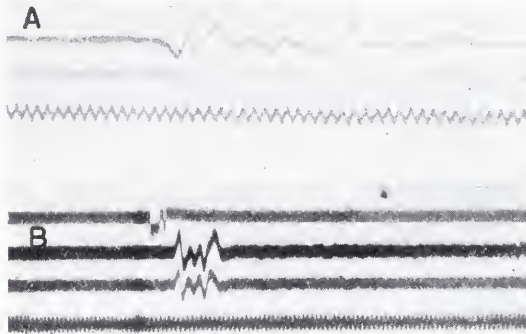


FIG. 2A, patellar records from patient ST. Signal was recorded on action current lines as in Fig. 1A; 2B, patellar records from dog D after lesion in the motor area of the right hemisphere.

pairs there remains the possibility of interaction as well as interconnection.

The pattern of the reflex is stereotyped although there are individual differences in the patterns obtained (20). It remained to be determined whether or not the stereotypy of the unilateral reflex was matched by a similar stereotyped pattern on the opposite side in the bilateral reflex. The complexity of the neural pathways and the muscle effectors might lead one to anticipate that only by chance would the individual motor units of homologous muscle pairs discharge in such a manner that duplication of pattern between pairs resulted. An analysis of the record patterns was undertaken to determine in what degree a reflex on one side of the body was like the same reflex on the opposite side.

II. Apparatus and procedure. Four elements of a six element Westinghouse oscillograph were used as recorders. Two elements recorded action currents. One of these recorded action currents from a muscle or group of muscles on the right side of the body, the other from the left side. Action currents were amplified by three-stage resistance coupled amplifiers, matched for frequency, amplitude, and wave-form. A third element produced a time line at 1,000 \sim (from a General Radio low frequency oscillator). The fourth element recorded the instant of application of the stimulus to elicit the reflexes. The stimulus

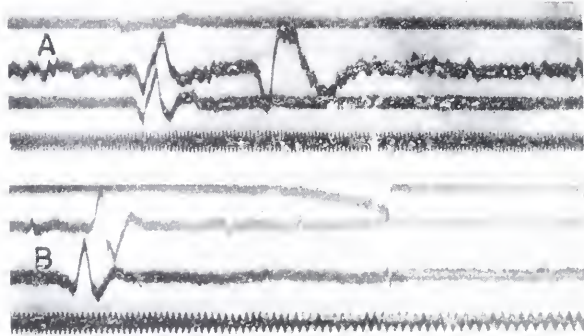


FIG. 3A, records of ipsilateral left patellar and crossed right patellar in dog D; 3B, records of ipsilateral left Achilles and crossed right Achilles in normal person.

was mechanical in all cases—a blow by a hammer, which struck a brass or steel plate placed over a point effective in eliciting the reflex. The contact of the hammer on the plate closed a signal circuit, which discharged into the fourth element.

Records were photographed on Eastman No. 1 35 mm. sensitized paper. A special camera, turned by hand, drew the paper past the recording slit of the oscillograph.

Electrodes made of brass strips, covered with Canton flannel soaked in supersaturated saline solution, were used for most of the records. They were held in place by rubber bands. In making the electrodes, a pair of brass strips were matched in size and in distance separating them by a second pair of brass strips. The size of the brass strips varied with the variation in the size of

the muscles to which they were applied, but homologous muscle pairs were covered with matched electrodes, in so far as was possible with the slight distortions of shape and size contributed by the Canton flannel covering.

Needle electrodes were used for several series of records taken on dogs. Except for the pointed tips, the needles were covered with bakelite varnish. The varnish provided insulation without adding materially to the thickness of the 20-gauge, platinum-iridium wire from which the needles were made. These electrodes were inserted about one cm. into the belly of the muscle and were held in place by adhesive tape.

The electrodes were located symmetrically on the bellies of homologous muscles. For the patellar reflex, location was determined by measuring to a point half-way between the anterior superior spine of the ilium and the upper margin of the patella. The upper edge of the proximal electrode was placed at this point. In the patellar reflex, the legs were clamped five inches apart so that measurement was considered necessary, but in the Achilles in man and the patellar in dog, the legs were placed as close together as was consistent with the maintenance of insulation, so that the location of the electrodes at homologous points was accurate without measurement.

With the exception of the jaw jerk, the stimulating device used in eliciting bilateral reflexes was always the same in principle, but the apparatus was adapted to each reflex. An insulated steel rod or thin piece of hard rubber was placed across the tendons of the executant muscles of the reflexes. The contact plate of brass or steel, mounted on bakelite or hard rubber, was placed on the rod or attached to the hard rubber substitute for the rod at the point midway between the tendons. The blow of a hammer on the contact plate served to elicit the reflex on both sides of the body and at the same time to actuate the signal circuit.

For the patellar reflex, a stand was built on a platform. *S* was seated on a chair placed on the platform. Three cross-pieces were clamped on the stand: a support for the legs, with adjustable clamps that prevented lateral movements; a steel rod, $\frac{3}{8}$ in. in

diameter, held against the tendons just below the knee-caps; and a pendulum, which could be released to fall against the rod from any height by means of a ratchet wheel, held stationary until time for the stimulus by a pawl. The pendulum was caught as it rebounded from the rod. For several Ss the rod also was allowed to recoil from the tendon and was caught by a magnet; this proved, however, to be unnecessary refinement, since no change was noticed in the records when the steel rod was clamped tightly against the tendons, and such slight vibrations as occurred after the fall of the pendulum remained undamped.

For the bilateral Achilles reflex, the contact plate of the signal circuit was mounted on a thin strip of hard rubber, which was placed against the tendons. The same technique was followed in eliciting the bilateral patellar reflex in dogs. A steel rod also was used for the patellar reflex.

For the unilateral reflexes (Achilles and patellar) and the jaw jerk, the procedure was like that used for the bilateral Achilles in man and the bilateral patellar in the dog. For unilateral stimulation, in both of the latter reflexes, the hard rubber strip was shifted in position so that it rested only on a single tendon with the contact plate directly above the tendon. For the jaw jerk, the contact plate was mounted on a small flat strip of hard rubber, which was placed against the chin. In the unilateral patellar in man, the pendulum was allowed to fall on the steel rod after one leg had been shifted out of contact with the rod. A stimulating device like that used for the Achilles was later substituted for this cumbersome technique, since no noticeable change occurred in the records when the substitution was made. Most of the data submitted below were obtained after the substitution.

With bilateral stimulation, jaw jerk records were taken successfully from 25 normal persons, knee jerk records from 17 normal persons and three patients with lesions in nervous tissue, Achilles records from 18 normal persons, and knee jerk records from four normal dogs and two dogs with cortical lesions. It was not possible to apply unilateral stimulation to the jaw jerk. In the cases of the other reflexes, unilateral stimulation on both

the right and left sides yielded knee jerk records on 13 normal people, Achilles records on 12 normal persons, and knee jerk records on four dogs. The normal individuals who served as Ss were, with the exception of one stutterer from whom Achilles and patellar records were taken, right handed and normal speakers. Handedness was checked by verbal inquiry; no tests were administered. The dogs were tested for handedness with a test devised by *Milisen* (13). The dogs, designated as A, B, C, and D, were left, ambidextrous, right, and left handed respectively.

Only those records were read in which the latency for the action current response was clear cut and in which the number of waves during the action current volley for one side did not exceed the number for the other side by more than six. The number exceeded six only in the human patellar; this number was chosen after inspection of the first records taken showed that some such criterion as this would have to be adopted to throw out those records in which mechanical artifacts and uncontrolled variables in the stimulus situation distorted the records. With bilateral stimulation, rejection of the record for one side threw out both records. Except in those cases where lesion abolished the crossed reflex in dogs, the ipsilateral response was not read unless accompanied by the crossed reflex.

In analyzing the records, one computed and five direct measurements were made on each reflex record. The measurements were: latency of the reflex, duration of initial action current wave measured to its crest, amplitude of the initial action current wave, total duration of the action current pattern of the reflex, number of waves occurring during the total duration of the action current volley, and frequency of the action current waves. Frequency is computed as the ratio between the number of waves and the total duration; because the total duration is measured in ms., this quotient is multiplied by 1,000 to reduce it to number of waves per second. All these measurements, with the exception of latency of the reflex, may be justified as indicators of the nature of the reflex pattern, but some of the measurements have other implications.

The latency of the reflex was defined as the time elapsing

between the stimulus and the beginning of the rise of the initial action current. All measurements of time were made to the nearest .25 ms. Since excitation of the cerebral hemispheres lengthens the normal latency (18) and removal of the influence of the hemispheres shortens the normal latency (3, 16, 17), the dominance of one hemisphere over the other might result in a longer normal latency of the reflexes controlled by the dominant hemisphere and a shorter normal latency of the reflexes controlled by the non-dominant hemisphere. The latencies also were checked for differences occurring between the reflexes elicited by bilateral simultaneous stimulation.

The duration of the initial action-current wave measured to its crest is of uncertain significance. *Lillie* (9) has written: "tissues with slowly developing bio-electric variations exhibit a slower rate of response and a slower subsidence of their activity; the muscular twitch, the chronaxie, the refractory period, and the summation-interval are relatively prolonged and the transmission is slow". On the other hand, *Erlanger, Bishop, and Gasser* (4) conclude that: "the time constants of all of the axon waves in a given nerve are approximately alike". These workers have demonstrated also that in a nerve made up of axon fibers with different conduction rates the time to maximum of the action current taken from the nerve increases rapidly and probably linearly in relation to the distance of conduction away from the point of stimulation. Our measurements taken from the action currents of muscle might therefore, according to *Lillie*, be extended into comparisons of conduction rate, chronaxie, refractory period, and summation period. However, the findings of *Erlanger, Bishop, and Gasser* with respect to nerve cast some doubt on the truth of such an extension in the case of action currents from muscle. Since, however, the muscle fibers are innervated by axons presumably of different conduction rates, any similarity in durations from homologous muscle pairs would indicate a similar order in the time of discharge and a similar anatomical arrangement of the controlling axons.

The amplitude of the initial action current was measured to the nearest .5 mm. from the base line of zero current to the crest

of the wave. Variables of which amplitude may be a function in our records are: number of fibers reacting, length of the muscle fibers before and at the end of contraction, phase relationships between action currents of individual fibers, distance between leads, and alteration of electrical resistance of the tissue or of the electrodes. Distances between leads for homologous muscle pairs were matched. Change in resistance of electrodes would result from evaporation of the saline solution, but approximately the same amount of drying for the two pairs of electrodes probably would occur in the time elapsing after their placement on the muscles. Other variables are regarded as uncontrollable in the reflex activity of the intact animal.

Total duration of the action current pattern, number of waves, and frequency of action current waves were included in analysis of the records mainly because of their dependence on the pattern of reflex activity. Total duration of reflex pattern was arbitrarily defined as the period of time between the beginning of the initial action current and that terminal peak or trough after which action current activity of one muscle group of a pair either was absent or was not accompanied by similar action current activity from the other muscle group of the pair. In counting the number of waves each peak, trough, and sharply angular turn in the action current line was assigned unit value. The angular turn was included because it was a function of the pattern, rather than because it had any definable significance.

Amplitude, total duration, and frequency were also measured because it was hoped they would give objective evidence of any pattern differences existing between action current records of homologous muscle pairs. Pattern changes from the normal have been noted when reflex centers were released from cortical control, namely, an increase in the size and duration of the action currents (16, 17) and a decrease in frequency (10). On the assumption that the muscle groups controlled by the non-dominant hemisphere are less subservient to cortical control than those controlled by the dominant hemisphere, one might expect greater amplitude of the initial action current wave, longer total duration of the reflex pattern, and a lower frequency from the reflex

TABLE I. *Average and SDs of measurements of reflex records taken on humans*

Reflex	No.	R.L.	L.L.	R.D.	L.D.	R.A.	L.A.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Jaw jerk	25	7.96 .88	8.02 .95	2.18 .73	2.05 .60	7.81 5.44	7.38 5.18	5.1 1.1	5.0 1.1	10.04 2.48	9.47 2.00	537 146	547 127
Bilateral patellar	17	18.98 1.27	19.05 1.08	1.92 .56	1.90 .47	2.40 3.11	1.67 .94	17 4	17 4	24.39 3.16	24.31 3.05	718 202	698 182
Unilateral patellar	13	18.22 .95	18.76 .65	1.92 .38	2.02 .53	2.72 1.83	1.99 1.10	17 3	17 4	24.12 1.53	24.19 2.45	720 184	699 168
Bilateral Achilles	18	33.68 2.46	33.48 2.51	1.79 .58	1.90 .74	4.63 2.30	2.67 1.90	8.1 2.5	7.9 2.1	11.76 1.99	11.93 1.71	695 187	668 138
Unilateral Achilles	12	32.78 1.61	32.91 1.62	1.82 .68	2.00 .84	4.43 1.45	3.93 2.01	7.8 2.1	7.4 1.4	11.80 .99	11.84 1.38	698 177	636 144

R.L. Right latency

L.L. Left latency

R.D. Right duration of initial action current

L.D. Left duration of initial action current

R.A. Right amplitude of initial action current

L.A. Left amplitude of initial action current

No. refers to the number of cases from which the averages and standard deviations were computed.

R.N. Right number of waves during action current volley

L.N. Left number of waves during action current volley

R.T.D. Right total duration of action current volley

L.T.D. Left total duration of action current volley

R.F. Right frequency of action currents

L.F. Left frequency of action currents

TABLE II. *Averages and SDs of measurements of patellar reflex records taken on dogs*

Method of stimulation	No.	R.L.	L.L.	R.D.	L.D.	R.A.	L.A.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Dog A: Bilateral	29	7.72	7.66	2.13	2.03	5.64	7.36	3.1	3.5	11.61	11.53	264	303
		.58	.53	.43	.51	3.54	5.25	.7	1.2	1.58	2.45	25	76
Unilateral	13-16	8.04	7.67	1.75	1.95			4.2	5.6	12.08	13.06	362	425
		.40	.43	.43	.59			1.0	1.7	2.60	3.04	106	93
Dog B: Bilateral	20	7.48	7.45	1.66	1.65	4.33	7.18	4.7	4.7	9.63	10.38	488	460
		.48	.49	.42	.44	1.91	3.50	1.2	1.2	.92	1.20	105	133
Unilateral	14-14	7.57	7.52	1.57	1.27			6.2	5.6	11.00	9.35	584	599
		.45	.43	.49	.28			1.4	2.0	2.39	1.26	166	204
Dog C: Bilateral	50	7.58	7.45	1.97	1.98	5.49	6.88	4.2	4.5	10.91	11.83	383	393
		.93	.77	.55	.58	2.53	4.61	1.2	1.5	2.00	2.50	96	157
Unilateral	39-26	6.70	6.74	1.92	1.73			4.0	5.5	11.69	10.18	346	559
		.33	.62	.38	.61			.8	1.7	2.08	1.77	90	160
Dog D: Bilateral	46	5.54	5.46	1.70	2.01	7.56	9.06	4.7	4.3	11.08	11.04	434	397
		.47	.44	.60	.59	4.11	4.81	1.8	1.3	3.10	2.06	139	112
Unilateral	36-58	5.48	5.33	2.06	2.16			6.0	4.0	10.70	9.30	570	438
		.59	.70	.75	.61			1.6	1.2	1.91	1.42	149	145

See Table I for key to column headings.

records of the muscle groups on the left side of a right handed person and on the right side of a left handed person.

III. Results.

Comparison of patterns and latencies from homologous muscle groups. Fig. 1 shows the type of records obtained with bilateral stimulation. Tables I and II present data obtained from the records. Records of the jaw jerk were taken from 25 cases and permit, therefore, more detailed statistical analysis of differences than was possible with other reflexes. Table III shows Pearson product-moment coefficients of correlation ranging from .55 to

TABLE III. *Correlation coefficients, differences, SE_{diff} , and CRs for measurements taken from reflex records of the jaw-jerk on the right and left sides*

	Latency	Duration	Amplitude	Number	Total duration	Frequency
r	.55	.65	.80	.79	.83	.58
Diff.	.06	.13	.43	.1	.57	10.
SE_{diff}	.18	.11	.67	.2	.27	26.
CR	.33	1.18	.64	.50	2.11	.38

.83 for measurements representing action current activity of the two sides of the body. These correlations were employed in computing the SEs of the differences for correlated measures. CRs were computed as the ratio between a difference and its standard error. A CR is arbitrarily considered to show a statistically significant difference, *i.e.*, one which cannot be accounted for by chance, when its value is three or greater than three. Table III shows one CR of 2.11, one of 1.18, and the remainder are below 1.0.

A series of bilaterally elicited reflexes on the same person might contain records in which there were no differences in latency and records in which the initial action current on the right side preceded that on the left, or *vice versa*. The differences between the latencies were small, and might be attributed to differences in time in stimulating the reflex and to variable differences in time required for the nervous impulse to course through the reflex arc. These small differences in latency, and

larger differences, sometimes obtained inadvertently in stimulation of the Achilles unilaterally, and failure to check the stimulating hard rubber strip from falling on the contralateral tendon, effected no noticeable change in the reflex pattern of either side.

Data for comparison of bilateral and unilateral stimulation of the patella and Achilles in man and the patella in dog are contained in Tables II and III. No consistent differences in pattern are evident as a result of the differences in stimulation. Bilateral stimulation appears, however, to result in longer latencies than unilateral stimulation. Although dogs A and B are exceptions, this tendency has been noted in many series of records, represented as averages in the tables. To check this further, 50 consecutive records with unilateral stimulation on the right side and 50 consecutive records with bilateral stimulation were taken on dog A. To elicit the reflexes, use was made of a hard rubber strip on which the contact plate was fastened, because it was believed this was a simpler system with less inertia than the steel rod on which the contact plate was placed and from which the plate was insulated by a small bakelite block. A CR of 7.17 was obtained, which established a statistically significant difference with bilateral stimulation giving the longer latency.

Variation of stimulus. The pattern of the reflex appeared to be persistently recurring, regardless of the side of the body from which it was taken, irrespective of any difference in latency that might exist between reflexes of the right and left side, and independent of the conditions of unilateral and bilateral stimulation. Therefore an attempt was made to vary the pattern by varying the placement of the stimulus. In the knee jerk, the stimulating pendulum was moved two inches to the left for a series of records and then two inches to the right of the rod center for another series of records. In the jaw jerk, the chin was struck first to the left of its middle and then to the right. It also was anticipated that this variation of placement of the stimulus might have a systematic effect on the latencies of the two sides. The nearer the stimulus was placed to the tendinous attachment of the muscle, the greater was the intensity of the stimulus on that side as com-

TABLE IV. *Averages and SDs of measurements of patellar reflex records when placement of stimulus is varied*

	No.	R.L.	L.L.	R.D.	L.D.	R.A.	L.A.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Midpoint	14	18.76 .12	18.89 .96	1.98 .59	1.93 .51	2.59 3.39	1.76 1.00	17 4	17 4	23.82 2.78	23.87 2.96	744 208	718 187
Left of midpoint	14	18.62 .94	18.55 .85	1.91 .68	1.93 .61	2.17 2.83	2.33 1.03	17 4	18 4	23.51 2.69	23.57 2.97	743 186	763 168
Right of midpoint	14	18.72 .94	18.88 1.09	1.88 .55	2.12 .47	2.65 2.76	1.58 .95	18 5	17 4	23.34 3.48	23.45 3.20	766 226	713 182

See Table I for key to column headings.

TABLE V. *Averages and SDs of measurements of mandibular reflex records when placement of stimulus is varied*

	No.	R.L.	L.L.	R.D.	L.D.	R.A.	L.A.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Midpoint	16	8.08 .87	8.03 1.04	2.10 .47	1.99 .64	8.25 4.77	7.33 4.96	5.0 1.3	5.1 1.2	9.29 1.94	9.05 1.85	561 165	574 142
Left of midpoint	16	8.36 .88	8.08 1.04	1.96 .65	2.06 .75	6.28 5.03	7.61 4.91	5.3 1.1	5.1 1.1	9.13 1.83	8.90 1.32	601 167	581 147
Right of midpoint	16	7.97 .67	7.77 1.11	1.75 .45	1.89 .51	7.79 4.59	5.78 3.41	5.3 1.5	5.2 1.6	8.71 2.12	8.66 1.54	633 181	611 158

See Table I for key to column headings.

TABLE VI. *Averages of measurements of patellar reflex records taken on patients with unilateral lesions*

	No.	R.L.	L.L.	R.D.	L.D.	R.A.	L.A.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Patient WA:													
Double	5	19.15	21.55	1.80	1.05	1.10	1.80	22	19	20.50	18.40	1.081	1.068
Single	5-3	19.55	20.00	1.45	1.33	3.60	3.20	23	14	24.10	23.00	950	618
Patient ST:													
Double	5	18.30	21.20	1.70	2.50	2.70	.60	25	14	24.60	21.30	1.009	656
Single	9-12	18.22	20.08	2.47	1.48	3.61	1.96	21	16	27.06	25.63	781	622
Patient HA:													
Double	7	19.70	19.11	2.21	2.54	.93	.79	13	22	26.89	37.21	483	798
Single	7-7	19.93	16.82	1.21	1.57	1.86	2.96	15	34	27.46	32.25	535	999

See Table I for key to column headings.

pared with the side more remote from the stimulus. Intensity of stimulus already has been shown to have an immaterial effect on latency in unilateral stimulation (21, 22), but its effect on pattern had not been explored. A change in the temporal order of excitation of receptors on the two sides also might have been effected by this change in the stimulus, but this cannot be demonstrated and is unlikely if one accepts the statement (2) that a single and almost synchronous afferent volley is set up by percussion on the tendon in a tendinous reflex.

The results are presented in Tables IV and V; the results of stimulation at a point midway between the patellar tendons in the knee jerk and at the center of the chin in the jaw jerk are repeated from Table I, but the averages and SDs have been changed slightly by the omission of those *SS*s for whom placement of the stimulus was not varied. No evidence of consistent change in pattern or latency has been discovered from this table, except that the amplitude is greater on the stimulated side.

Variation of central control. To vary the central control, bilateral and unilateral patellar reflex responses were recorded from neural lesion cases in which the reflex of one side was released from the influence of higher centers. These cases included three patients and two dogs, C and D, in the latter of which lesions were produced by electro-cautery in the motor area of the dominant hemisphere. The data for the patients are presented in Table VI, and for dog C in Table VII. The averages from records of the second dog are omitted, but such changes as occurred will be described. A spinal transection at the upper lumbar level was performed on dog C, and data from records taken after the operation also are presented in Table VII.

Patient WA had suffered upper motor neuron lesions in the left hemisphere; patients ST and HA were right and left sided hemiplegics respectively. The side affected by the lesion showed in each case a shorter latency, a larger number of waves, a longer total duration of action current pattern, and a higher frequency of action currents; these characteristics were independent of the method of stimulation. The differences between the latencies were, however, increased by bilateral stimulation in patients WA

TABLE VII. *Averages and SDs of measurements of bilateral patellar reflex records taken on dog C before and after lesion in the motor area of the left hemisphere (4/25/34) and after spinal transections (6/24/35)*

	No.	R.L.	L.L.	R.D.	L.D.	R.A.	L.A.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Normal	50	7.58 .93	7.45 .77	1.97 .55	1.98 .58	5.49 2.53	6.88 4.61	4.2 1.2	4.5 1.5	10.91 2.00	11.83 2.50	383 96	393 157
After lesion 4/25/34	15	7.13 1.04	8.05 .60	1.00 .21	1.25 .22	1.10 .43	1.30 .53	8.7 1.4	7.4 .8	11.60 1.71	12.63 1.10	756 102	583 24
4/26/34	31	7.00 .48	7.15 .43	1.53 .41	1.71 .46	3.62 3.32	5.01 5.51	8.8 1.0	8.6 1.2	12.79 .80	12.73 .88	692 97	678 112
5/2/34	14	6.71 .50	7.09 .43	2.00 .40	2.16 .39	3.29 1.46	5.86 2.61	4.9 1.5	3.0 .0	11.23 .56	11.39 .71	440 142	264 17
5/7/34	16	7.39 .34	7.28 .37	1.59 .32	2.34 .44	1.47 .84	3.59 1.56	4.9 1.7	6.0 1.4	10.48 2.38	10.48 1.90	468 131	572 103
5/23/34	12	7.08 .46	7.35 .36	1.77 .39	1.75 .40	4.00 1.47	1.92 .89	3.6 .6	5.2 .7	10.00 1.46	8.13 1.07	373 88	641 91
After transection	30	6.42 1.18	6.14 .71	2.78 .75	2.59 .88	17.77 5.48	7.80 3.60	4.5 2.0	4.0 .9	14.69 2.97	13.79 3.31	299 104	308 93

See Table I for key to column headings.

and ST and very materially decreased by bilateral stimulation in patient HA.

The patterns of reflexes of the right and left sides were not markedly altered although the number of waves, total duration, and frequency were changed. The pattern of the affected side retained a semblance of the pattern of the unaffected side. Fig. 2A demonstrates these points with a record from patient ST.

In the two dogs, the pattern was changed from the normal, but the unilateral lesion appeared to result in a bilateral change, which did not alter the similarity between patterns of the two sides. The number of waves was increased on both sides, but the total duration did not vary significantly from the normal; the frequency of action current waves consequently was increased by the experimental lesion. Fig. 2B shows the increase in frequency. As shown in Table VII, both the number of waves and the frequency approach the normal values with the passage of time. The results were similar when obtained with unilateral stimulation.

Table VIII shows a tendency for the right latency to be shorter than the left after the lesion in the left hemisphere. This difference in latencies was not present either in the records taken with unilateral stimulation or in the records taken from the second dog after cortical lesion.

After spinal transection, the latencies were lowered, the duration of the initial action current to the crest and the total duration increased, and the frequency decreased. The similarity of pattern between the two sides remains, since a change on one side was paralleled by the same change on the opposite side.

Variation in recording from effectors. When needle electrodes are used in recording muscular response, the intention of *E* is to reduce the area of the muscle from which he picks up electrical activity. *Adrian* (1) has shown, in comparing records in which the size of the electrodes and the distance between them was varied, that with large electrodes the response is an average from the whole muscle, but that, with small electrodes, the inter-polar field is much more sharply defined and a few fibers responding out of phase with the remainder will have a much

TABLE VIII. *Averages and SDs of measurements of patellar reflex records taken on dogs with needle-electrodes*

	No.	R.L.	L.L.	R.D.	L.D.	R.A.	L.A.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Dog A:	18	8.07 .69	8.44 .45	1.10 .39	1.15 .33	1.11 .75	2.58 3.62	9.6 1.6	8.4 1.8	9.74 1.55	9.83 1.41	991 102	852 137
Dog B:	28	7.68 .65	7.80 .80	1.13 .30	1.13 .36	1.13 .79	.68 .24	8.7 2.5	8.0 1.8	10.15 1.92	9.40 1.99	856 170	871 196
Dog D:	14	6.02 1.18	5.93 1.18	1.38 .36	1.34 .40	1.86 2.22	1.71 1.80	16.4 1.7	10.9 1.7	11.14 1.35	10.95 1.36	938 132	996 94

See Table I for key to column headings.

greater effect on the total response. *Forbes* and *Barbeau* (5) agree that insertion of needle electrodes into the muscle causes a relative increase in the part played by fibers with which they come most nearly in contact. However, since action current records were obtained with needle electrodes in a muscle at rest, while its antagonist was stimulated through its motor nerve, these *E*s contend that the influence of other fibers in the limb is not excluded.

Our records were obtained from the right and left quadriceps femoris muscles of dogs during reflex activity. The pairs of needles were placed about one cm. apart and at homologous points in the muscles, in so far as this was possible when the selection of points for insertion was made from the surface of the skin covering the muscles. In comparing Table VIII with Table II, we note an increase in number of waves and in frequency as a result of using needle electrodes. This increase was interpreted as support of *Adrian's* statement that a few fibers responding out of phase with the rest will have a much greater effect on the total response when small electrodes are used. The records from homologous pairs were, however, similar in pattern. Similarity must have depended on placement of electrodes at approximately homologous points in the muscle pairs; heterologous placement would result in contact with motor units discharging at different times in the two muscles and consequently phase differences would distort the pattern. Since, however, needle electrodes also average the effect of more remote fibers, some resemblance between records from homologous muscle pairs would be maintained regardless of the exact placement of the electrodes.

It also will be noted in comparing Tables VIII and II that the latencies obtained with needle electrodes are longer than any obtained with surface electrodes. This may result from the longer time required for the potential from a smaller area of the muscle to assume the magnitude necessary for recording in conjunction with the differences in the times of discharge of the motor units in the reflex. With respect to the latter fact, the volley of reflex impulses may have a temporal dispersion of 3 ms. or longer (2). Probably those motor units nearest the

needle electrodes would by chance more frequently be later in this 3 ms. period than the earliest discharging motor units picked up by the much larger surface electrodes.

The crossed reflex. When the patellar reflex in the dog is elicited unilaterally, the ipsilateral response is frequently accompanied by a crossed response identical in direction of movement with the patellar reflex. *Sherrington* (23) has recorded the same phenomenon in decerebrate cats. The identical crossed response is, however, according to *Sherrington*, a function of the intensity of the stimulus administered to the opposite side; a weak stimulus excites a crossed reflex identical with the reflex of the stimulated side, but a strong stimulus results in an antagonistic crossed reflex. Although a crossed response does not always appear in our records, contralateral flexion was never noted and, for an uncontrolled and varying intensity of stimulus, contralateral extension was frequently elicited. The most obvious and probably most significant difference between *Sherrington's* technique and ours is that his records were taken from decerebrate animals, whereas ours were taken from intact animals. A second difference between the results obtained and the techniques employed was the elicitation of ipsilateral inhibition of extensors by direct stimulation of the peroneal nerve in *Sherrington's* records and the elicitation of ipsilateral excitation by indirect stimulation in our records. These differences in technique probably are related to the differences in results obtained.

Sherrington also noted from his myograms that the contralateral response was weaker than the ipsilateral. We found it necessary in order to record this reflex to remove from the circuit all the resistance which ordinarily was introduced to keep the amplitude of the action current waves within the limits of the width of the 35 mm. paper. Because the removal of the resistance left the two action current recording units no longer matched for amplitude, no measurements of amplitude were made for comparison between the ipsilateral and crossed reflex.

Table IX presents measurements of the ipsilateral reflex response and the crossed reflex response. The average latencies of the crossed response are always longer than those of the ipsi-

TABLE IX. *Averages and SDs of measurements of unilateral and crossed patellar reflex records taken on dogs*

	No.	R.L.	L.L.	R.D.	L.D.	R.N.	L.N.	R.T.D.	L.T.D.	R.F.	L.F.
Dog A: Ipsilateral	13-16	8.04 .40	7.67 .43	1.75 .43	1.95 .59	4.2 1.0	5.6 1.7	12.08 2.60	13.06 3.04	362 106	425 93
Contralateral	16-13	8.58 .91	9.37 .76	2.80 1.58	2.87 1.02	5.6 2.1	3.9 1.3	13.72 3.12	10.92 2.81	404 104	389 173
Dog B: Ipsilateral	14-14	7.57 .45	7.52 .43	1.57 .49	1.27 .28	6.2 1.4	5.6 2.0	11.00 2.39	9.35 1.26	584 166	599 204
Contralateral	14-14	9.09 .95	7.79 .88	1.41 .34	1.98 .75	5.4 1.2	5.8 1.9	8.81 1.60	10.88 3.41	628 167	575 223
Dog C: Ipsilateral	39-26	6.70 .33	6.74 .52	1.92 .38	1.73 .61	4.0 .8	5.5 1.7	11.69 2.08	10.18 1.77	346 90	559 160
Contralateral	26-39	6.83 .48	7.20 .73	3.81 .89	1.37 .74	4.8 1.8	6.0 2.4	11.79 1.53	10.38 1.84	410 107	602 272
Dog D: Ipsilateral	36-58	5.48 .59	5.33 .70	2.06 .75	2.16 .61	6.0 1.6	4.0 1.2	10.70 1.91	9.30 1.42	570 149	438 145
Contralateral	58-36	5.94 1.01	5.77 .77	2.16 .90	2.10 1.01	5.8 2.1	6.2 1.6	10.94 2.52	11.06 2.47	537 206	576 187

See Table I for key to column headings.

lateral response. In the individual records, the difference between the latencies ranged from zero to 4.5 ms.

No other consistent differences in the measurements made were noted. The pattern of the crossed reflex is similar to and often synchronized with the pattern of the ipsilateral reflex, as shown in Fig. 3A.

A crossed Achilles reflex was elicited in two *Ss* after a short period of bilateral stimulation. This reflex from the unstimulated side is doubtless comparable to *Wendt's* crossed patellar reflex (25) elicited after a similar period of bilateral stimulation. An action current record of the crossed Achilles is presented in Fig. 3B. The latency of this response is longer than the latency of the stimulated side, but the pattern is similar.

IV. Discussion. The absence of significant differences between latencies or characteristics of the action current pattern suggests the absence of consistent differences between reflexes of the two sides of the body. Substantiation of the hypothesis introduced at the beginning of this paper would have necessitated a longer latency on the right side of right handed individuals, since presumably the normal inhibitory effect of the cerebral hemispheres upon latency would be greater from the controlling or left hemisphere. Records from individuals reveal no consistent trends in this direction, nor do the averages of average records from individuals. Measurements which upon the basis of previous experiments might have been expected to show differences between the sides were: amplitude of initial action current, total duration of action current pattern, and frequency. These measurements have not revealed differences between the right and left sides.

If, however, the gradient between the two hemispheres or the control which the hemispheres exert over the reflex centers is increased by unilateral lesion, differences in both latency and pattern become evident. The latency of the reflex, released from the control of its hemisphere, is shortened and the total duration of the pattern is lengthened in humans. This is in accord with previous findings (7). That amplitude of the initial action current wave is not increased on the affected side, as might have been

anticipated from previous work, is not significant since the amplitude of only one wave of the pattern was measured. The increase in frequency on the affected side in humans and on both sides in the dog is, however, in direct contradiction to the findings of *Lindsley* (10). He cauterized the dominant hemisphere of rats and described the frequency on the affected side as decreased from the normal. His data show, however, that the frequencies on the unaffected side are increased after the operation; this part of his data is in accord with our findings on dogs. The resolution of the discrepancy between our results is probably dependent upon further research.

If there are no significant differences between the patterns from homologous muscle pairs, it follows, if the scope of the measurements is wide enough, that there is very great similarity. Inspection, as well as measurement, shows that with bilateral stimulation the records from symmetrical muscles not only may be similar, but that often they appear to be synchronized. It has been demonstrated that this similarity may exist when the conditions of elicitation, central control, and means of recording from the effectors are varied.

If the picture of the reflex as presented by *Creed*, *Denny-Brown*, *Eccles*, *Liddell*, and *Sherrington* is accepted, the following series of events occur: "when the tendon of a muscle is drawn upon very suddenly as, for instance, by a tap at some point where it is not supported by underlying bone, *e.g.*, the patellar tendon as it passes over the knee-joint, or the Achilles tendon at the ankle, a number of tension receptors are subjected to a sudden brief stretch, so that they send to the cord an almost synchronous volley of nerve-impulses, which, by summation of central excitatory states excite a number of motoneurons to discharge"; "the volley of reflex impulses has a temporal dispersion sometimes of three sigma or longer"; "each motoneurone innervates on the average rather more than one hundred muscle-fibers".

Similarity of reflex records from the two sides of the body indicates similarity of this complicated course of events from initiation to muscular contraction. The implication is that the

motoneurons are similarly distributed anatomically and that they discharge in a similar temporal order. The temporal order of discharge is dependent upon the rate at which the central excitatory state develops. A central excitatory state is built up by the arrival of excitatory impulses. Since the number of afferent fibers stimulated is controlled by the strength of the stimulus, the rate of development of the central excitatory state should be altered by a stronger stimulus, and the temporal order of discharge of the motoneurons changed. Changing the intensity of the stimulus does not, however, significantly alter the pattern, although it increases the amplitude of the initial action current and probably, therefore, the number of motoneurons excited. This fact seems to oppose the theory presented above concerning the course of the reflex. A test more crucial than varying the intensity would be variation of the pattern of stimulation of afferent neurons, which would be possible with an electrical stimulus in which the rate of change of the stimulating current was a controlled variable.

Wendt has shown that the integrating paths from the receptors for a reflex of one side to the contralateral effectors for the same reflex are of relatively low resistance. The frequency of occurrence of the crossed patellar response in dogs, and the occasional presence of the crossed, unstimulated Achilles response after a period of bilateral stimulation in human Ss, may be presented as additional evidence that the pathways are of low resistance. Anatomical interconnection makes functional interaction possible. Bilateral and approximately simultaneous stimulation has resulted in many cases in longer latency than unilateral stimulation. The exceptions to the lengthening of latency might be accounted for by the uncertainty of the instant of application of the stimulus adequate for elicitation of the reflex, *i.e.*, the stretching of the muscle. This result should be checked with electrical elicitation of the reflexes, since time of application of the electrical stimulus is subject to more rigid control than the mechanical stimulation used in this study. If the latency continued to be longer for simultaneous than for successive elicitation of the reflexes of homologous muscle pairs, more conclusive

evidence would be at hand concerning interaction between the reflexes.

That the crossed patellar response in dogs may be of the same latency as the ipsilateral response allows a conclusion to be drawn concerning the number of neurons in the ipsilateral patellar reflex arc unit. *Jolly* (8) believed that two neurons were involved in the arc with a single synapse interposed between them. *Fulton* (6) comments, concerning *Jolly's* conclusion, that to attempt to infer the number of synapses traversed from a finite time interval, *e.g.*, two sigma, *Jolly's* 'reduced reflex time', is pure speculation. That a tendon reflex may involve only two neurons still, however, finds its way into textbooks (6, 11, 14).

The conclusion here is drawn that the patellar reflex arc involves at least three neurons. This conclusion rests upon two assumptions: (1) that the contralateral reflex requires an internuncial neuron, and (2) that there is a delay of neural conduction at the synapse. For the first assumption, we have the authority of *Creed*, *Denny-Brown*, *Eccles*, *Liddell*, and *Sherrington* (2): "according to current anatomy none of the afferent root fibers or their collaterals trespass across the median longitudinal plane of the cord; a crossed reflex effect therefore involves always an internuncial neurone." For the second assumption, a recent experiment by *Lorenté de No* (12), with two pathways of equal length and conduction rate, and a synapse in one of the pathways, has shown this delay to measure from .50 to 1.36 ms. and roughly to be in inverse relation to the strength of the stimulus. It follows, therefore, that, if the ipsilateral reflex may have the same latency as the crossed, it must have the same number of synapses. Since the contralateral reflex is believed to have at least three neurons, the ipsilateral patellar must also have at least three neurons.

The measurement of jaw jerk latency in the normal human being is, to the best of our knowledge, the first to appear in the literature. The action current response is of peculiar interest since the gross movement response is usually not perceptible to either *S* or *E*. The following statement from the American Medical Dictionary undoubtedly refers to gross movement

response: "it is seen only rarely in health, but is very noticeable in sclerosis of the lateral columns of the cord."

V. Summary. Action current records of simultaneous bilateral reflex responses were taken from the quadriceps femoris, gastrocnemius and masseter muscles. Records were taken from both normal and neurological cases. The records were analyzed in regard to latency, duration of the initial action current, total duration of the reflex pattern, number of waves occurring during total duration, and frequency of action currents.

1. No significant differences in latency and pattern of records from homologous muscle groups in normal *SS* were discovered. The differences that did exist gave no demonstrable correlation with handedness.

2. There was a marked similarity between the reflex patterns of two homologous muscles. This similarity was found to occur independent of the following factors: (a) conditions of bilateral and unilateral stimulation; (b) differences in latency between action current responses from the right and left sides of the body; (c) placement and intensity of the stimulus as it was directed and divided between the two sides of the body; (d) unilateral lesions of the higher centers of the central nervous system; (e) spinal transection; (f) variation in size and intimacy of contact of electrodes with the effectors, as determined by the substitution of needle electrodes for brass-strip electrodes; (g) the passage of the effect of the stimulus applied unilaterally to the effectors of the opposite side of the body (as in the crossed patellar reflex of the dog and the crossed Achilles reflex of man). This similarity of pattern was interpreted as indicating similarity in anatomical arrangement of all units involved in the reflex and similarity in the temporal functioning of these units.

3. Evidence was obtained that the reflex on one side influences the same and concurrent reflex on the opposite side, lengthening the latency. Establishment of this effect of bilateral, simultaneous stimulation is dependent upon exact timing of administration of the stimulus. The effect was interpreted to mean that there is functional interaction between two homologous reflexes simultaneously elicited.

4. Both latency and pattern of the reflex response of the affected side may be altered by unilateral neural lesion of the higher centers. It therefore is probable that, although the gradient between the normal control of the right and left hemispheres over the reflex centers appears not to be manifest in action current reflex records, this gradient so may be increased, by lesions to one side, as to be reflected in reflex records.

5. In dogs, the patellar reflex of the unstimulated side was equal to or longer than the patellar reflex on the stimulated side. Equality of latency between ipsilateral and crossed reflexes was interpreted as evidence that the patellar reflex arc unit has at least three neurons, rather than two, as has sometimes been asserted.

6. The action current latency of the jaw jerk of normal persons was determined.

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THE EFFECT OF TRAINING UPON THE HANDED- NESS PREFERENCE OF THE RAT IN AN EATING ACTIVITY

by

ROBERT MIISEN

1. Introduction. During the last ten years the phenomenon of sidedness has become of increasing interest because of its possible relationship to stuttering, reading, and spelling disabilities. There is disagreement as to the importance of sidedness in these disorders, yet enough evidence, both clinical and experimental, has been offered to make it desirable to investigate more fully here the basic factors underlying one aspect of sidedness, namely, handedness.

It is obvious that studies of handedness in human *S*'s involve limitations due to inadequacy of case history reports, difficulties inherent in the task of measuring 'native' and trained handedness, and the difficulties of controlling the handedness factor sufficiently for experimental purposes.

Oates (2) reports the work of *Lewis*, the only attempt to study experimentally the influence of shifting handedness in human beings. He shifted 12 subnormal children from the right to the left hand and after five months all 12 developed stuttering. After the left handed training was abandoned, stuttering disappeared in all cases. He did not attempt to determine how complete the shift had been.

Peterson (3) reports an attempt to study the effect of environmental influence upon handedness by binding the preferred hand of the rat. He did not succeed in changing handedness by this method.

Tsai and *Maurer* (4) were the first to report the fact that rats have handedness. They also indicated that a lack of vitamin *B* in the diet seemed to develop a tendency toward left handedness.

The question as to whether handedness preference is the result of training or of native pre-disposition has been important to workers in the field of laterality for some years but thus far no intensive study of the type described in this paper has been reported.

The purpose of this study is to show experimentally some of the influences of training upon handedness preference in the rat. As presented, it must be considered a preliminary report. While the number of rats used in this experiment precludes definite conclusions, the trend of results is definite enough to justify early presentation. An attempt will be made to answer the following questions: (1) can handedness be explained merely on the basis of habit formation? (2) is handedness more difficult to influence in older than in younger rats? (3) is the handedness of the female rat more easily influenced than that of the male rat? (4) does peripheral deficiency influence handedness preference? (5) does the circular-cage test used in this study measure adequately the effect of training which the rats receive in the training cage? (6) what variations in handedness appear as a result of training?

II. Apparatus. Two test cages and one type of training cage were used. The first test consisted of a circular cage with base one foot in diameter and sides cylindrical in shape and 10 in. high. A vial was set in the center of the bottom of the cage. The mouth of the vial protruded about $\frac{1}{4}$ in. above the plane of the bottom. The size of the mouth of the vial was such that the rat could obtain food only by reaching with one hand.

The training cages were composed of square passageways about 8 in. long placed side by side. They varied in size with the age and size of the rats. The passages were large enough to permit the rat to crawl in without being too crowded, but too small to allow it to turn around while in the cage. A slit approximately $\frac{1}{2}$ in. wide was cut in the base of the passage either on the extreme right or left side. Beneath the slit was placed a trough of finely crushed bread, making it necessary for the rat to reach through the slit to get the bread.

The second handedness test used in this study required an

apparatus which resembled the shape and size of the training cages. The essential difference from the construction of the training cages was the placement of the slit in the base, which (in the testing cage) ran transversely across the passage instead of parallel to it as in the training cages.

III. Procedure. All rats were forced to eat from the training cage. The daily number of food prehensions by each rat fell between the extremes of 300 and 500. Thus 10,000 prehensions per month for every rat in the training cage would be a minimum estimate of the amount of one-handed training.

In order to note the effect of this training, all rats were tested at intervals of about one month. A modification of the technique of *Tsai and Maurer* (4) was used. In this test a rat was placed in the circular cage and allowed to make 50 prehensions from the vial. The prehensions were tabulated according to hand used. The motor set of the rat was disturbed by pushing it away from the vial after every five prehensions. By this method the influence of position and fatigue upon handedness preference was largely eliminated. Hereafter this test will be referred to as the 'circular-cage test'. A careful check was made upon all the rats by the use of this test, and special attention was paid to rats that did not show any change in handedness resulting from their training in the training cage.

IV. Results. The rats used in this experiment were divided into five groups.

1. Nine male rats, one year of age, were tested for handedness preference and then forced to eat in a training cage with the non-preferred hand for nine months. All these rats retained their original handedness in spite of nine months training of the non-preferred hand.

2. Six male and seven female rats, age three months, were selected at random and compelled to feed with their left hands in the training cage for three months. Their handedness preference was tested only after they had been eating with the left hand in the training cage for one month. This test revealed that four males and five females were left handed, and that two males

and two females were still right handed. The same results were obtained for the tests on the second and third months. At the end of the third month, all rats were forced to eat with their right hands. Two females died before the fourth test was given on the fourth month. One of four left handed males shifted completely to the right hand. Two of the three left handed females shifted to the right hand. In one, the shift was complete and in the other the shift was more than half complete. The tests after the second and third months yielded the same results, except that the partially shifted female became more thoroughly right handed.

3. One female and four male rats, three months of age, were tested by 10 prehensions of food in the circular-cage test before being placed in the training cage. This test revealed that three males and one female rat were right handed and one male rat was ambidextrous. These rats were placed in the training cage and were forced to eat with their left hands. After a month they were tested; one male and one female had become ambidextrous and three males remained right handed. The test at the end of the second month showed that two male rats had shifted to complete right handedness. The two males that had shifted to the left hand retained their left handedness and one right handed male became partially ambidextrous (this change was contrary to the training). The remaining right handed male remained right handed. The test results for the fourth month of right handed training were the same as those for the third month.

4. Five male and four female rats, 23 days of age (just after weaning), were selected at random. They were forced to eat with their left hands in the training cage for two months and were tested after one month of training. At this time, there were four left handed males, three left handed females, one right handed female and one ambidextrous male. The test results for the second month were the same. Following this test all rats were forced to eat with the right hand in the training cage for four months. At the end of the third month of right hand training, four left handed male rats were left handed, and one ambi-

dextrous male shifted completely to the right hand. Two of the three left handed females shifted completely to the right hand and the one right handed female remained right handed. The test for the fourth month yielded the same results.

5. Two male and two female rats, age three months, were tested for handedness and the middle finger of the preferred hand was removed. The rats were not placed in the training cage but were allowed to eat with the stock rats. They were tested a month after the operation and again four months after the operation. All rats in this group retained their original hand preference in both tests.

17. Discussion.

Can handedness be explained merely on the basis of habit formation? If hand preference in rats is to be explained entirely on the basis of habit formation, one would expect that (1) sufficient training will change original hand preference; (2) individuals whose entire unimanual feeding activity since birth has been with one hand will exhibit a preference for that hand; (3) the amount of shift should be proportional to the amount of training; and (4) one should be able to shift and re-shift in terms of direction of training.

These four conditions are not fulfilled. In group 1, nine male rats, age one year, were forced to use their non-preferred hands for nine months (more than 90,000 prehensions per rat). At the end of all this training the rats still preferred to use the originally preferred hand. In other words, we might say that the rats were forced to eat with the non-preferred hand for a quarter of the life span without shifting to that hand. This appears to be sufficient training to change handedness if handedness is due to habit formation alone.

In group 4, nine rats were forced to eat with the left hand immediately following weaning. This probably was the first consistent and purposeful unimanual activity in which these rats had participated. After they ate with their left hands for one month, they were tested; one rat was right handed and another ambidextrous, while seven were left handed. After 10,000 prehensions each, the rats again were tested and the results were

identical with the first test. If handedness were due to training alone, all the rats whose entire unimanual feeding activity since birth had been with the left hand should use that hand when placed in a hand preference situation. Two of the nine rats persisted in choosing the right hand in spite of the left hand training; hence they present another exception to any explanation in terms of habit formation alone.

In habit formation the amount of shift should be proportional to the amount of training. In the nine year-old rats, no amount of training brought even the slightest shift. In the majority of young male rats a shift was impossible in spite of three months or more of training. In one female and two male rats a partial shift took place in the direction of the training, but all the further training of two months did not complete the shift. This tends to show that amount of shift in handedness is not directly proportional to the amount of training.

If handedness is directly controlled by training one should be able to shift handedness and re-shift it in terms of training direction. This condition existed in only one of 11 rats shifted during the course of this study. Of these, 10 were shifted from the preferred hand to the non-preferred hand. They were given four months of training for the originally preferred hand but were unable to shift back to it.

This is strong evidence upon which to base a statement that handedness is not entirely due to habit formation; on the other side of the question, much evidence is presented to show that handedness is not due entirely to native qualities. Ten rats were able to shift their handedness preference, either partly or entirely, after a period of training. If handedness preference were due entirely to innate qualities, training should not change their preference. Moreover, one female rat was successfully shifted three times. If handedness were purely innate it should be as difficult to shift a young rat as an old one, but this study does not bear out that generalization—although some younger rats could be shifted, it was impossible to shift older ones.

In summary, this study indicates that handedness preference is due to the interaction of native sidedness and environmental

influence. In the majority of rats, native sidedness seems to be the more powerful.

Is handedness preference more difficult to influence in older than in younger rats? Not one of the nine old males placed in the training cage manifested a shift in handedness. After nine months of eating with a non-preferred hand, which is equivalent to more than 90,000 prehensions per rat, these old males still preferred to use the other hand when given their preference. A group of 16 young male rats did manifest a tendency to be influenced by the training, since five of them shifted either partially or completely to the non-preferred hand. This shift took place within three months, as compared to nine months training of the old males.

These results seem to indicate that the older the animal is the more firmly rooted are its handedness tendencies.

Are there sex differences in the plasticity of handedness preference in rats? This question is of special interest since we know of relatively great sex differences in stuttering, reading disability, spelling disability, color blindness, and shifted handedness among human beings. Milisen and Johnson (1) studied a group of 265 children with changed handedness. The study indicated that three times as many girls as boys were able to shift preference with relative completeness from one hand to the other.

In the present study it was possible to shift five out of 16 young male rats either partially or completely, by training which amounted to from 10,000 to 30,000 prehensions per rat. Five of eight females were shifted either partially or completely after an equivalent period of training. Only 29 per cent of the males, as compared to 63 per cent of the females, were shifted.

Thus it would seem that females are more easily shifted than males. If further research tends to bear out this finding, we may have a working basis for studying sex differences in stuttering.

Does peripheral deficiency influence handedness preference? Four rats were tested for handedness and then the middle finger of the preferred hand was removed by operation. They were tested a month after the operation and again four months later.

In each case the loss of a finger had no effect upon hand preference, although the preferred hand was not as proficient as it had been, or as the non-preferred hand might have been if it were used.

It is interesting in this connection to consider briefly whether injury to the central nervous system affects handedness. *Peter-son* (3) reports that lesions in the superior portion of the motor area of the hemisphere contralateral to the preferred hand caused a shift in handedness in the rat.

Does the circular-cage test used in this study measure adequately the effect of training which the rats acquire in the training cage? If the rat received definite handedness training from eating in the small, cramped alley-way of the training cage, could the amount of that training be measured by a testing set-up which completely changes the configuration in all respects except that an eating situation is used in both instances?

If the testing set-up is inadequate, a new test fashioned after the training cage should bring out conflicting results, especially in rats who have not indicated any effect of training.

Ten rats who had not indicated any influence of training in the circular-cage test again were tested by the training cage test. Some rats were tested twice; hence we can make 18 comparisons. Of these 18 comparisons between the results of the circular-cage test and the training-cage test, 15 rats showed identical preferences on both. In three comparisons, rats testing right or left handed on one test were ambidextrous on the other. In the last three cases the direction of error did not favor either test. Hence we can be assured that the circular-cage test is a fair measure of the degree of training received in the training cage.

What peculiar variations in handedness appeared as a result of training? One behavior variation was manifested by a male rat who seemed to receive negative stimulation from the training cage. He developed right handedness while being trained in the use of the left hand.

One group of rats, two males and one female, could be shifted only partially. They changed from pure right handedness to

ambidexterity, but further training of the left hand did not make the shift complete. These rats could be shifted back to their originally preferred hand with relatively little training.

Another group of rats, three females and three males, were shifted completely from the preferred to the non-preferred hand after a period of training, but the attempt to shift back again was not successful.

A further variation was manifested by one female rat who was able to shift from one side to the other after a training period of not more than three months. This rat first exhibited left handedness. Her right hand was trained and she slowly changed to right hand preference. Her left hand then was trained and she became left handed again. With some training of the right hand she became right handed once more.

It appears that male rats more often than female rats retained their original handedness in spite of training. Also, the handedness of some rats may be influenced partially but not completely, the resulting condition being that of ambidexterity. This occurs more frequently with the males. The majority of animals that were shifted could be shifted only once. The shift then would be relatively complete and it appeared impossible to re-establish the original handedness by training. One female rat had a plastic handedness mechanism which was highly susceptible to training.

VI. Conclusions. This study points toward the following conclusions with regard to handedness in rats.

1. Handedness of some but not all rats can be changed by training.
2. Handedness can not be explained solely on the basis of either habit formation or innate tendencies, but rather by an interaction between them.
3. Disability of the preferred hand does not seem to influence handedness preference.
4. The older the animal becomes, the more firmly fixed his handedness preference seems to become.
5. Female rats seem to be more easily shifted in their handedness preference than male rats.

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THE INFLUENCE OF EMPHATIC RESPONSE ON FREQUENCY OF STUTTERING

by

C. VAN RIPER

I. Introduction. For many years speech pathologists have been confronted by the popular belief that stuttering is often caused by imitation, and that the disorder may be transferred from one person to another through social inheritance. In the course of clinical examination several parents of stutterers have reported that the onset of their children's disorder occurred soon after they had been observed imitating some other stutterer. Many clinicians are prone to regard these reports with some scepticism, having known cases in which only one of a number of children who mocked a stuttering playmate began to stutter. They ask the question: "Why did not these other children stutter?"

Then again, stutterers frequently report that they seem to stutter much worse after listening to the speech of other bad stutterers, and that they experience great discomfort during such listening. Furthermore, during various experiments which necessitated a situation where a stuttering speaker addressed a group of stutterers, the latter were observed to give emphatic responses ranging from obvious breathing abnormalities to facial grimaces.

Without delimiting the nature and scope of this emphatic response to stuttering, a simple experiment was devised to measure what effect, if any, the hearing and seeing of stuttering would have upon a stutterer's speech.

II. Experimental procedure. The stutterer was brought into the examining room and introduced to the two *E*s, one a normal speaker and the other a severe stutterer. He was then instructed as follows: "The purpose of this experiment is to determine

how often you will stutter when you attempt to say words after someone else has pronounced them. Fifty words will be pronounced one at a time by the normal speaker. As soon as you hear each word, watch the second experimenter who will give you the signal to speak by raising his pencil. The time interval between pronouncing and the signal to speak will be three seconds. Be sure to watch the experimenter as he pronounces the word." Following the reading of these instructions the fifty words were pronounced and attempted according to the procedure outlined in the instructions. This was termed Situation A. Both the normal speaking *E* and the stuttering *E* checked independently the number of stuttering spasms, and after each attempt the stutterer was asked whether he had stuttered or not.

After the 50 words had been read by the normal speaker and the number of spasms checked, the same list of words was again pronounced, this time by the second *E*, who stuttered or pretended to stutter badly on each word. This was termed Situation B. The same procedure used in Situation A was employed for checking stuttering spasms and the same instructions were used. Only those spasms upon which all three individuals agreed were counted. Sixteen adult stutterers from the speech clinics of the Universities of Iowa and Minnesota were used in the investigation. The fifty words used in the study were: banana, dresses, frock, stutter, police, broken, girl, fist, marvel, venture, weighty, lottery, tremble, statistics, queen, parcel, drink, necessary, restaurant, clerk, operation, small, voice, language, often, clings, slowly, thinks, black, people, urged, two, utmost, well, you, artificial, those, trick, wished, grandfather, smoke, skillfully, contain, have, except, pronounce, know, likes, thumbnail, and plays.

III. Results. The results of this experiment demonstrated that the stutterers had more spasms when the stuttering *E* pronounced the words than when the normal speaker pronounced them. The average difference between number of spasms experienced in Situations A and B was 7.1. When the CR was computed, it equalled 2.5, giving a probability of 99 chances out of 100 that this difference was a true difference. Actually, only one case of

the 16 stutterers tested showed a decrease in number of spasms when the stuttering *E* pronounced the words. The average number of spasms in Situation A was 10 with an SD of 7.7, and in Situation B it was 17.1 with an SD of 8.3.

Certain observations were made which may be of some suggestive value. Certain stutterers seemed to stutter in a manner very much like that used by the pronouncer, although they claimed never before to have stuttered in such fashion. Other suggestible cases seemed to vary the duration of their spasm according to that had by *E* in pronouncing the word. It should also be mentioned that the small number of cases used was due to the fact that many stutterers had no difficulty when pronouncing words after they had been spoken. Stutterers entering the clinic for the first time proved to be the best *S*'s. The percentage of agreement between *E*s and stutterers varied between 83 and 98 per cent, but little error should be attributed to this source since only those spasms on which both *E*s and the stutterer agreed were counted. Finally, it should be mentioned that overt signs of emphatic response were often noted during the stuttering *E*'s performance of the word.

II'. Summary. When stutterers attempted to pronounce words which had just previously been pronounced by a normal speaker or bad stutterers, they stuttered more frequently in the latter situation. These results are attributed to the effects of the emphatic response to such stimulation.

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